THE USE OF WING PARTS FOR MONITORING ENVIRONMENTAL RESIDUES

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ABSTRACT

This report reviews the literature on the use of wing parts for surveying toxic chemical residues. The possibility of using wing parts of harvested game birds, which are submitted as part of an annual survey, to monitor environmental residues is evaluated. The studies reviewed employed whole defeathered wings, wing muscles, wing bones and feathers as media for chemical analysis. The focus of attention has centered on persistent environmental residues (i.e. whole defeathered wings: organochlorines, wing muscles: mercury, wing bones: lead from spent shot, wing feathers: mercury). Other than studies of DDT residues in whole defeathered wings and lead residues in wing bones, little attention has been focused on the relationship of contaminants in the wing parts to other body tissues.

RÉSUMÉ

Ce rapport fait état des écrits sur l'emploi d'éléments d'ailes pour l'analyse des résidus de produits chimiques toxiques. On y examine la possibilité d'utiliser des parties d'ailes de gibier aviaire, reçues dans le cadre d'une enquête annuelle, pour contrôler les résidus environnementaux. Les études passées en revue se servaient des ailes complètes déplumées, des muscles, des os et des plumes d'ailes comme sujet d'analyse chimique. L'attention s'est arrêtée sur certains résidus environnementaux persistants (i.e. des organochlorés dans les ailes déplumées, du mercure dans les muscles, du plomb de cartouche dans les os et du mercure dans les plumes). Mis à part l'examen des traces de D.D.T. dans les ailes complètes et de plomb dans les os des ailes, on a porté peu d'attention aux liens existants entre les contaminants dans les parties d'ailes et ceux contenus dans les autres tissus du corps.

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1.0 INTRODUCTION

The impact of toxic chemicals on avian populations is a problem of major concern in wildlife management. Numerous studies are available in the published record documenting the widespread occurrence of contaminants in tissues of non-target organisms. Besides being a threat to the health of the bird species, the accumulation of residues in animals can often serve as an indicator of environmental quality, geographical dispersion of toxic chemicals and as an early warning signal of possible risks to man. The surveillance of toxic chemicals and their interactions with organisms through the use of well-designed monitoring programs will yield valuable information for assessing the effects of environmental pollution.

It is difficult, if not impossible, to find an alternative to using organisms as indicators of the availability of biologically active materials in the environment - especially if one is attempting to determine contamination in selected food chains. Furthermore, monitoring of residues in the biota is advantageous over measuring pollutants in the physical environment in that the concentrations of accumulated substances in the former are often easier to measure. In addition, the levels of residues can sometimes be correlated to an impact on the organism.

Certain criteria were recognized by various workers for what they considered to be an ideal vertebrate species for monitoring chemical contamination, including birds (Moore, 1966; Anon., 1974; National Academy of Sciences, 1975; Luepke, 1979; Ellenberg and Dietrich, 1981). Some aspects to be considered when choosing a species for biological monitoring are discussed elsewhere (Appendix A). To briefly summarize, the selected species should have a continuous distribution with stable population densities and be easily collected. Its behavior, activity, physiology and food habits should be well known. It should be easily identified, aged and sexed. The species should assimilate a variety of pollutants over space and time. In addition, it should be sedentary in its habits if measurements of local contaminants are monitored, or it should have an extensive range if residue levels are surveyed over a large area.

A fundamental consideration in selecting specimens for chemical analysis is the feasibility of obtaining them. Traditionally, monitoring of pollutants in birds has taken the approach of either killing individuals or collecting eggs for analysis. This, of course, would be impractical for rare or endangered species. Several sampling strategies have been employed which allowed for evaluation of exposure to residues without further culling the population. One source of biological material is the use of dead or dying specimens recovered in the field. As part of the National Pesticide Monitoring Program, the U.S. Fish and Wildlife Service periodically analyzes residues in tissues of Bald Eagles (Haliaeetus leucocephalus) found dead throughout the United States (Ohlendorf, 1979). Samples of small migratory songbirds that died from collision with man-made structures during their autumnal and vernal migratory flights have also been successfully employed for pesticide analysis (Johnston, 1974; 1975). Similarly, road kills have been reported to be useful biological samples for analyzing environmental residues (Johnston, 1976; Luepke, 1979). No established methodical pattern of sampling is possible with these approaches, yet they do provide some information on wildlife exposure to pollutants. These procedures are useful supplements to other more systematic types of environmental monitoring.

Another approach is to exploit existing collection practices which were originally designed for other purposes. By using these "ready-made" samples collected for other intentions (game bird surveys, museum collections) the population being studied is not further persecuted. The use of museum collections for the study of environmental contamination has previously been reviewed and the advantages and shortcomings of using this resource have been discussed (Rick, 1975).

This report will document the possibility of using wing parts of harvested game birds, which are collected annually to determine the species, age and sex composition of the harvest, to monitor environmental residues. Information on the Canadian Species Composition Survey (SCS) is reported in Appendix B and elsewhere (Cooch et al., 1978).

Four types of wing samples have been employed for chemical analysis: (1) whole defeathered wings, (2) wing muscles, (3) wing bones, and (4) wing feathers. The objective of this report is to collate the published record on the use of wing collections or wing parts of birds for surveying environmental pollutants. It was assumed that all published residue data are valid. No attempt was made to reject results on the basis of dubious sampling methodology and/or inadequate quality assurance. The suitability of the structure as a medium for chemical analysis and biological monitoring is discussed.

2.0 WHOLE DEFEATHERED WINGS

Whole wings from ducks are submitted annually by cooperating hunters to federal agencies (Canadian Wildlife Service, U.S. Fish and Wildlife Service) for biological examination and as a reconnaissance of the productivity of harvested waterfowl. Many species of ducks are available. A list of the species that are submitted for the SCS in Canada is found in Table 2 of Appendix B. The U.S. Fish and Wildlife Service has chosen the wild Mallard, *Anas platyrhnchos*, and the Black Duck, *A. rubripes*, for use in the National Pesticide Monitoring Program (Heath and Prouty, 1967; Dustman *et al*., 1971). Those two closely related species are relatively abundant, readily collectable and their combined range covers much of the continental United States. Both species are omnivorous (Appendix C) and migratory - factors which allow them to encounter and accumulate pollutants in a large segment of the environment. Data derived from the surveys have been used for quantifying temporal and geographical trends of organochlorine residues in duck populations. Those investigators believed that the trends of pesticide levels in the ducks reflected the trends in the environment (Heath and Prouty, 1967). They realized that Mallards and Black Ducks are not "ideal" indicator species because their migratory tendencies may not allow for the detection of local contamination. However, they suggested that this problem could be resolved by also monitoring localized environmental samples (water, soil, crops).

Prior to the use of wings as a monitoring medium, a study was conducted on the metabolic fate of an organochlorine pesticide (DDT) in whole duck and on the relationship between residues in wings compared to other body tissues (Dindal and Peterle, 1968; Dindal, 1970). Radio-labeled Cl^{36}-p,p'-DDT and technical DDT were applied aerially to a 4-acre (1.62 ha) marsh at a rate of 0.2 lb/acre (0.224 kg/ha). Analysis of the technical DDT showed it was composed of 85.3% p,p'-isomer, 11.0% o,p'-isomer and 4% unidentified isomers. Following the single application, 112 Mallards and Lesser Scaup, *Aythya affinis*, were released into the marsh. The ducks (age unknown) were sampled at various exposure periods (6 hours to 130 days). The dissected tissues of 104 ducks were analyzed for total DDT residues, p,p'-DDT, DDE, DDD and DDMU. Systematic sampling showed that dietary assimilation of DDT residues in the birds was rapid, with residues being detected in tissues following 6 hours of exposure (Dindal, 1970). Residue levels in whole defeathered wings were found to correlate with those in breast muscle, breast skin, kidney and uropygial gland of Mallards and Lesser Scaup (Table 1). Lower correlation coefficients existed between wing and brain, liver, pancreas, gonad, adrenal and thyroid gland residues. No relationship was found between the wing and breast feather residue data.

In 1964, a pilot study was carried out with Mallard and Black Duck wings from New York and Pennsylvania (Heath and Prouty, 1967). Following segregation of the wings into groups by species, age (but not sex), and state of kill, they were pooled (25 wings) to reduce individual variability. It was not revealed how the size of the pools were derived (statistically or otherwise). Although variation in residue levels among individual wings was reported to be considerable (Heath and Prouty, 1967), the magnitude of this variation was not given. Prior to analysis, the distal joint and feathers were removed from the wing by trimming with scissors or a saw. Then the remaining wing was chopped and blended into a homogeneous pool (of 25 individual wings) with a commercial food cutter (Heath and Prouty, 1967; Heath, 1969). Essentially, the wing sample consisted of feather bases, skin, subcutaneous fat, muscle and bone. The analytical results demonstrated that DDT, DDD, DDE and dieldrin were detectable in the wing pools. Since this initial study, defeathered wings of Mallards and Black Ducks have been used for residue analysis on a regular basis (every 2 to 3 years). The overall objectives, justification and procedures of this sampling program have been reported (Johnson et al., 1967; Dustman et al., 1971; Jacknow et al., 1986).

The first nationwide effort was conducted during the 1965-66 and 1966-67 hunting seasons (Heath, 1969). The wings from the two seasons were analyzed for organochlorine residues and the data were combined to provide baseline measurements for monitoring trends in future residue levels. Subsequent sampling was scheduled at three year intervals thereafter (Heath and Hill, 1974; White and Heath 1976; White, 1979; Cain, 1981; Prouty and Bunck, 1986). A summary of the major findings of those monitoring studies is found in Table 2. As reported, the acquired information permitted regional comparisons of residue levels and provided a basis for following geographical and temporal trends. Despite the inherent variations (sampling and analytical processes), the residue data showed differences among flyways, groups of states, and sometimes, among individual U.S. states (Heath, 1969). However, those workers cautioned that interpretation of the results should not be on a statewide basis (as in sampling and expression of residue data) because of the mobile nature of the two species (Heath and Hill, 1974; White, 1979). They also argued that the consistency of the wing monitoring data, the consistency of the migration patterns of the ducks, and the rapid assimilation of organochlorine residues in those species are factors which can allow the investigators to associate wing residue data with the average level of residues in the aquatic environment in the U.S. state of collection (Heath and Hill, 1974). The precision of monitoring residues in wings will vary from U.S. state to U.S. state, depending on the number of wings sampled and the variability of residue levels in the environment where the birds were collected (Heath, 1969).

Although the findings may be difficult to interpret as indications of local contamination, one study has demonstrated that waterfowl wings can be used to demarcate localized pollution within a state (Fleming and O'Shea, 1980). They examined DDT residues in whole defeathered wings of Mallards collected from hunters in Alabama. According to results from the nationwide pesticide surveys, wings of Mallards wintering in Alabama consistently had the highest mean DDT and DDE residues compared to all other states (Heath, 1969; Heath and Hill, 1974). In 1972, the mean DDT and DDE levels in those wings were 12.9 and 6.2 times the national averages, respectively (Fleming and O'Shea, 1980). Wings from the 1978-79 harvest were segregated by age and sex, as well as by the county of collection. Chemical analyses of wing pools (5 wings per pool) showed that the total DDT residues from two adjacent counties in northern Alabama were 10.8 and 18 times higher than the other counties. The sites of heaviest DDT contamination were located near a former DDT manufacturing plant, and pollution from that source was believed responsible for the elevated levels of DDT in wings from the two counties. Such definable differences of DDT residue levels in wings suggest that by categorizing wings to finer geographical subdivisions, it is possible to pinpoint areas of heavy localized contamination.

Analyses of individual wings were reported to be useful for showing seasonal, as well as regional differences in residue levels (Heath and Hill, 1974). Adult Mallard wings from three areas in California were analyzed individually to examine possible differences in pesticide levels as the hunting season progressed. Wings of male and female Mallards collected in October-November from San Joaquin Valley counties showed higher levels of DDE (1.2 to 10X) and DDT (2 to 3.5X) compared to those harvested in January. Similarly, wings collected from the Sacramento Valley in October also had higher DDT levels (3X higher for male and female ducks) than those obtained in January. The authors postulated that birds collected early in the hunting season, before the full-scale migration, were mostly local populations reflecting the contamination in the area of collection. The residue data for individual wings were highly variable, ranging from 0.49 to 41.72 ppm DDE (wet weight) in October and 0.18 to 7.13 ppm DDE (wet weight) in January. Those variations were greater than observed for pooled wing samples (Heath and Hill, 1974) but the effect of this variance on pooled wing data was not investigated. Overall, individual wings of both sexes collected in October from the intensively farmed San Joaquin and Sacramento Valleys had higher median values of DDT (3 to 5X) and DDE (3 to 24X) than wings from ranching counties in California. Individual wings of male and female Black Ducks (adults) collected from coastal counties of New Jersey in October contained mean DDE and DDT levels that were two to three times higher than wings collected in December (Heath and Hill, 1974). In addition, those wings were reported to have significantly higher DDT (15 to 18X) and DDE (5 to 12X) than individual wings harvested from upstate New York at about the same time (October). In both of the studies, the sample sizes were small with groups ranging from 2 to 13. Furthermore, the individual wing residue data were highly variable. This was true even for wings of the same species, age and sex which were obtained from the same location (county) at the same time.

During the 1980-81 season, wing pools (3 to 10 wings) of Pintails, Anas acuta, submitted by hunters from five regions in California, were analyzed for DDE, DDT, dieldrin, HCB and PCBs (Ohlendorf and Miller, 1984). Overall, the concentrations of all organochlorine compounds were low (below 1.0 ppm, wet weight). Comparisons of geographical trends showed higher ($p < 0.01$) levels of all organochlorine residues in wings from southern California than wings from the northern portion of the state. The residue data also indicated that wings of male ducks contained higher DDE levels ($p < 0.05$) than wings of females. Furthermore, it was reported that wings collected later in the hunting season - presumably from ducks that were in the area for a longer period of time - had higher mean DDE concentrations than wings collected earlier. It was postulated that the ducks were accumulating DDE during their stay in their wintering habitats of California.

Pesticide residue levels in wings of 12 species of Australian waterfowl were monitored in 1977-78 with an approach similar to the U.S. surveys (Olsen et al., 1980). DDE was the predominant residue in the wing samples and there was a general association between DDT residue in pooled wings and DDT use at the collection sites. In addition, adult ducks had greater residue loads (p,p'-DDE, p,p'-DDD, p,p'-DDT, total DDT and dieldrin) than juveniles. Moreover, molting adults had higher residue levels than non-molting adults. This was postulated to be either a result of fat mobilization during the molt or due to continual exposure in a contaminated environment since the birds are less mobile during their molt (Olsen et al., 1980). However, it appears that more studies are required before a definitive statement on this topic can be made. Highly significant correlations were established between total DDT in wings and that in brain ($r = 0.999$), liver ($r = 0.988$), fat ($r = 0.975$) and breast muscle ($r = 0.907$). They extrapolated the DDT levels in wings to that in fat and found that half of the pooled samples of Pacific Black Duck, Anas superciliosa, and 73% of individual adult ducks had residue burdens exceeding the limits allowed in food for human consumption - established at 7 ppm by the National Health and Medical Research Council of Australia.

Whole defeathered wings of American Woodcocks, Philohela minor, have also been employed for pesticide measurements. The results of four U.S. surveys are summarized in Table 3. In some cases, distinct geographical, temporal and age difference in residue levels were indicated (Stickel et al., 1971; McLane et al., 1973; McLane et al., 1978; McLane et al., 1984). Organochlorine pesticide levels were highest in wings collected in the southern states and New Jersey, while northern and midwestern states had the lowest values. Lower DDE (6.82 ppm to 8.79 ppm, lipid weight), PCBs (1.64 ppm to 5.58 ppm, lipid weight) and mirex (1.09 ppm to 1.54 ppm, lipid weight) residues were found in wings collected in 1971-72 than those in 1970-71. Furthermore, wings from immature woodcocks collected in Louisiana had lower mirex contamination than adult wings.

The temporal changes in organochlorine residue concentrations in the Woodcock wing sampling program for the 1970-71, 1971-72, and 1974-75 seasons were reviewed recently (McLane et al., 1984). No definitive trends in adult wing residues were evident during the time frame covered by those three surveys. Graphic representation of the mean levels of DDE showed a significant decline from 1971 to 1972 (from approximately 9 to 6 ppm, lipid weight), but the values reported in wings sampled in the 1972 and 1975 surveys did not differ significantly. PCB levels in woodcock wings collected in 1972 decreased significantly compared to levels found in 1971 (from approximately 6 to 2 ppm, lipid weight) but a significant increase (2 to 3 ppm, lipid weight) was detected in levels collected in 1975. Similarly, mirex and heptachlor epoxide residue levels in the 1975 survey were higher than those found in wings collected during the 1972 season. Comparison of residues in immature woodcock wings collected in 1972 and 1975 (wings of immature woodcocks were not sampled in 1971) also showed some temporal changes. DDT levels declined significantly from 3.08 ppm in 1972 to 1.83 ppm (lipid weight) in 1975. Levels of mirex (0.69 to 0.87 ppm), dieldrin (0.95 to 1.55 ppm) and PCB (1.70 to 2.81 ppm) residues increased from 1972 to 1975 (indicated in parentheses for each chemical). The concentrations of DDE, DDD and heptachlor epoxide remained about the same.

Attempts have been made to quantify the relationship between residue levels in wings and other body parts. Captive Black Ducks of both sexes chronically dosed with 10 ppm of p,p'-DDE for one breeding season and given untreated food for 2 years were found to still carry about 10% of the DDE residues. The levels of DDE in wings of both male and female ducks correlated statistically with DDE residues in the carcass on both a wet weight ($r = 0.984$, $N = 16$, $p < 0.001$) and lipid weight ($r = 0.98$, $N = 16$, $p < 0.001$) basis (Longcore and Stendell, 1977). Similarly, Peterson and Ellarson (1978) found a positive relationship between DDE residues in wings and carcasses of adult male Oldsquaws, Clangula hyemalis, from Lake Michigan ($r = 0.92$, $N = 14$, $p < 0.001$). Clark and McLane (1974) found statistically significant correlation coefficients ($r = 0.579$ to 0.946) when comparing residue levels (DDT, DDD, DDE, PCBs, dieldrin, heptachlor epoxide and mercury on a lipid weight basis) in wings to breast muscle or carcasses of field-collected woodcocks. But when the residue data were recalculated according to the percentage of fat in the tissue samples, significant differences for DDT, DDD and PCB concentrations among the three tissues were found.

The levels of DDE and DDT in wings correlated ($p < 0.01$) on both a wet and lipid weight basis with the levels in the carcasses of Pintails (Ohlendorf and Miller, 1984). The residue concentrations in wings were similar to those in the carcasses when expressed on a lipid weight basis. Since the carcasses of these ducks contained on the average twice as much fat (percentage-wise) as wings, in effect, wing residues would be approximately half that of carcasses when the concentrations are expressed on a wet weight basis. Dilworth et al. (1974) also reported a statistically significant correlation (r = 0.99) between total DDT levels in whole defeathered wings and those in breast muscle of 15 freshly killed woodcocks from New Brunswick. The residues were expressed on a dry weight basis because wings submitted by hunters for game bird surveys may have variable amounts of dessication. It was suggested that the precision of estimating DDT levels in breast muscle on a lipid weight basis from DDT levels in wing on a dry weight basis would be influenced by the variation in lipid content of the former. They found that the percent fat of breast muscle samples collected in September-October 1971 (1.79%) was significantly lower than those collected during that same time in 1972 (2.88%). No reasons were advanced to account for this difference. The moisture content of these samples did not differ significantly. The results suggest that determination of high correlation coefficients does not necessarily provide sufficient rationale for the use of the respective regression equations in predicting residue levels in other tissues. Further quantification is required.

3.0 WING MUSCLES

Four investigations have used the muscle tissue stripped from the radial and ulnar portions of waterfowl wings for the analysis of mercury residues and another study used wing muscle for analysis of DDE (Table 4).

These surveys showed that wing muscles can be employed as a medium for measuring mercury and DDE contamination in these waterfowl. The objective of two of the studies was to determine total mercury levels in wing muscles as an indication of levels in the breast muscle and hence, a measurement of dietary intake of the heavy metal in consumers. Highly positive correlations were obtained between mercury concentrations in wing and breast muscles (on a wet weight basis) in the species of ducks examined (Vermeer and Armstrong, 1972b; Pearce et al., 1976). The correlation coefficients ranged from 0.726 for Blue-winged Teal (Anas discors) to 0.978 for Common Goldeneye (Bucephala clangula). The correlation coefficients for mercury concentrations in wing muscle and breast muscle of Mallards and Black Ducks were $r = 0.959$ and $r = 0.950$, respectively. The results suggest that mercury in wing muscles can provide representative information for predicting levels in breast muscles but it should be pointed out that those ducks were freshly killed and were not from hunter surveys. The reported ratios of wing/breast muscle mercury also varied among the examined species. Levels of DDE in Brown Pelicans (Pelecanus occidentalis) were highly correlated between carcass and wing muscle on a lipid weight basis ($r = 0.796$, $p < 0.01$), and between wing and breast muscle on a wet weight basis ($r = 0.954$, $p < 0.001$) suggesting that wing muscles would be useful for predicting organochlorine levels in breast muscle, as well (Ohlendorf et al., 1985).

It appears that the ratio for each species under investigation must be calculated before one can apply this relationship for predicting residue uptake in consumers. The wing/breast muscle ratio of mercury residues in immature ducks was demonstrated to be independent of the sex (Vermeer and Armstrong, 1972b). At this time, there is only scant information on the accumulation of elemental and organic residues as a function of age and sex of the animal. Obviously, such knowledge is a prerequisite for interpreting data from residue surveys.

If consistent wing/breast muscle relationships can be established for a variety of environmental pollutants in different avian species, then chemical analysis of wing muscles can potentially be useful for determining temporal and regional levels of contamination. Pearce *et al*. (1976) reported that breast muscles of ducks collected during September 27 to October 4 had lower mercury concentrations (0.29 to 3.04 ppm, wet weight) than those collected 6 weeks earlier (0.92 to 7.45 ppm). This was believed to be a result of the immigration of less-contaminated ducks and/or the immigration of ducks from less polluted areas. Furthermore, birds sampled near the source of mercury pollution (chlor-alkali plants) had higher mean levels of mercury (0.29 to 3.04 ppm, wet weight) than those (0.10 to 0.48 ppm) collected farther downstream from this point. The results show that the timing and location of sample collection can greatly influence the residue data.

In a study on adults and chicks of Eastern Great White Egrets (*Egretta alba modesta*), Honda *et al*. (1985; 1986a) have shown that the variation of the metal contents in muscle is dependent on the muscle composition which changes during growth suggesting, therefore, that accumulation of metals may vary with the development process of organs and tissues. Honda *et al*.

(1986b) found that the Black-eared Kite (Milvus migrans lineatus) eliminated most of its body mercury during molting thereby decreasing tissue mercury concentrations during that period.

4.0 WING BONES

Wing bones (humerus, ulna and radius) have been used to assess avian exposure to residues - in particular total inorganic lead from gun pellets (Table 5). Although this structure can function as a medium for lead analysis, there is only limited information on accumulation of other residues in wing bones even though waterfowl are exposed to several potentially toxic elements (i.e. arsenic, tin, selenium, manganese, cadmium, chromium, copper and nickel) upon ingestion of spent shot (Hall and Fisher, 1985). There are, however, some studies on the deposition of toxic chemicals in other bones (Table 6). Szefer and Falandysz (1986) reported concentrations of iron, zinc, manganese, copper, lead, cadmium, cobalt, nickel, chromium and silver in various bones of Greater Scaup (Aythya marila) overwintering in Gdansk Bay. They found significant differences in most metal concentrations between different bones - the highest concentrations of iron were in the skull and the lowest were in the wing bones; the distribution of iron was similar to that of copper; and leg bones contained the highest amounts of zinc, manganese and lead while wing bones were characterized by the lowest levels of these metals. In their study on Eastern Great White Egrets, Honda et al. (1985) found concentrations of iron, copper, lead, nickel, cadmium and mercury were highest in the sternum and lowest in the humerus. Concentrations of iron, copper, lead, nickel, cadmium and mercury increased with moisture content leading the authors to suggest that accumulation of these metals in the bones depends on the blood content.

Finley et al. (1976b) fed first-year Mallard drakes 1, 5 and 25 ppm of lead (in the form of lead nitrate salts) for up to 12 weeks and reported no significant differences in lead concentrations between the tibia (2.09 ppm, dry weight) and wing bone (1.81 ppm, dry weight) among treatment groups. Regression analysis showed a direct correlation between lead levels in these bones ($r = 0.98$). High lead residues in the tibia were accompanied by high lead residues in the radius-ulna. Mourning Doves (Zenaida macroura) fed 0, 1, 2 or 4 No. 8 shot showed no differences in bone lead concentrations among treatment groups or between control and treatment groups dosed with 1 lead shot pellet, but those dosed with 2 and 4 pellets had significantly higher bone lead concentrations than their controls (Buerger et al., 1986). The Mourning Doves dosed with 1, 2 or 4 No. 8 lead shot also exhibited higher mortality than the control birds. In another study, Longcore et al. (1974b) dosed 4-month-old Mallard drakes with a single No. 4 size lead shot (about 1.4 g). Birds began to die 4 days after dosing and deaths continued for 20 days. At death, the blood, brain, breast muscle, gall bladder, heart, kidney, liver, lung, pancreas, spleen and tibia were removed and analyzed for lead residues. Live ducks that were similarly dosed were sacrificed at the same time for comparison of lead levels in the tissues. Results are summarized in Table 7. Liver and kidney lead concentrations were higher in ducks that died than sacrificed ducks. The highest lead levels were found in the pancreas and kidney of ducks that died, and in the pancreas and tibia of sacrificed birds. In both groups, the lead level in tibia was found to increase linearly with the length of time after dosing. The lead concentration in the tibia also increased according to the rate of erosion of the lead shot (Longcore _et al_., 1974b). Although, to our knowledge, no studies have been carried out on the half-life of lead in avian bones, the half-time residence life of inorganic lead has been estimated to be 600 to 3,000 days in bone of other species (Harrison and Laxen, 1981).

Those experimental studies have shown that lead residues in the liver indicate current exposure and lead in bones (tibia) indicates the history of exposure (Longcore _et al_., 1974b). The results demonstrated that the uptake of lead in bone is rapid (within 4 days) and the subsequent loss is slow. It may be possible to assume that an immature bird with high lead content in wing bones was exposed to high levels in the environment (Longcore _et al_., 1974b; Finley _et al_., 1976a). In adults, however, high lead levels in wing bones may be indicative of acute high level exposure or chronic low level exposure. Although the presence of lead in bone would be evidence for exposure, it is unlikely that one can differentiate between acute or chronic poisoning (Longcore _et al_., 1974b), unless other tissues were also examined.

The lead content in wing bones of field-collected waterfowl have been reported to cover a wide range of concentrations (Table 5). This is hardly surprising, since wing bones or bones in general serve as long-term storage sites for absorbed lead from all sources (Longcore _et al_., 1974b; Mudge, 1981). Bagley and Locke (1967) found mean lead levels in bone (tibia) of waterfowl with no known history of exposure to range from 2 to 13 ppm wet weight. Some investigations have shown that ducks with bone lead residues over 20 ppm were likely to have been exposed to lead (White and Stendell, 1977). Immature Mallards collected from eight hunting areas in the U.S. during the hunting season had wing bone lead levels ranging from trace levels (<0.5 ppm) to 345 ppm dry weight (White and Stendell, 1977). The means ranged from 2.99 ppm to 27.85 ppm. The result showed that areas with the highest mean lead levels in wing bones also had the highest percentage of wing bones with greater than 20 ppm lead residues. In another study, wing bones of Canvasback, Aythya valisineria, from Chesapeake Bay were found to have low mean lead concentrations (7.8 ppm, dry weight) (White et al., 1979). The mean lead level of livers was 0.14 ppm, indicating these ducks were not suffering from current lead contamination.

Studies on wing bone lead content of waterfowl that were dying from lead poisoning showed high concentrations of the metal in all cases. Lesser Scaup found dying in Illinois during the spring had lead levels ranging from 12 to 138 ppm (dry weight) in their wing bones (Anderson, 1975). The lead content in the ulnae of Canada Geese, Branta canadensis, found dying in Colorado was also reported to be high. A mean lead concentration of 41 ppm and a range of 7 to 389 ppm dry weight was found in this bone (Szymczak and Adrian, 1978). Seemingly healthy wild geese averaged 4 ppm of lead in the ulna with a range of 2 to 11 ppm. Analyses of lead in ulnae of Canada Geese raised in captivity showed similar values (mean = 5 ppm, range = 2 to 20 ppm). Those workers also compared ulnar lead levels of dead birds and those captured alive. Dead geese had significantly higher (46 ppm) lead concentrations than sacrificed geese (27 ppm). The variability of lead levels observed in bones of field-collected waterfowl makes accurate assessment of the degree of lead exposure difficult. However, it may be possible to diagnose birds with lead residues exceeding 20 ppm in their bones as individuals which have been exposed to this contaminant, as described by other authors (Longcore et al., 1974b; White and Stendell, 1977).

Geographical differences in wing bone lead levels have been documented. Two nationwide surveys, one in the U.S. (Stendell et al., 1979) and one in Britain (Mudge, 1981), have been performed and their major findings are summarized in Table 8. In the U.S. study, wings of seven species of ducks collected in the 1972-73 harvest surveys were grouped by species, age and state. The radius and ulna were removed from intact wings that were not damaged by lead pellets. The bones of up to 75 immature duck wings or up to 25 adult wings were pooled for lead analyses. Immature Mallards provided the best data set for comparisons of lead burdens among wings from the four flyways because of their wide distribution and large sample size. The median lead level (5.6 ppm, dry weight) and the percentage (17%) of wings with greater than 20 ppm of lead were reported to be highest in ducks from the Atlantic Flyway, followed by the Mississippi and Pacific. Wings of ducks from the Central Flyway had the lowest median lead residues (0.8 ppm). Regional variations in lead levels were also detected. Immature Mallards from the northern states of the Atlantic Flyway had higher median lead residue levels (5.8 to 8.9 ppm) in wing bones than those from the southern states (3.3 to 3.9 ppm). The situation is reversed for lead in wing bones of immature Black Ducks, which showed higher levels (5.3 to 5.7 ppm) in ducks from the southern states than those collected from the northern states (2.0 to 3.8 ppm) of the Atlantic Flyway. When the states of Oregon and Washington in the Pacific Flyway were further subdivided into zones (2 zones for each state), some localized regional differences were found. Immature Mallard wing bones from western Washington had higher mean lead residues (23.6 ppm, dry weight) than eastern Washington (8.4 ppm). In addition, the mean lead levels in wing bones of immature Mallards from the Columbia River Basin of Oregon were higher (44.7 ppm) than those from the remainder of the state (15.3 ppm). The Columbia River Basin is an area of known lead pellet contamination (Stendell et al., 1979).

In the British survey, the tissues (gizzard, liver and/or wing bones) were collected from hunters during the 1979-80 and the 1980-81 hunting seasons. Some waterfowl specimens found dead in the wild were also analyzed (Mudge, 1981). Mallards had the largest sample sizes over a wide range of areas and their wing bone lead content (values greater than 20 ppm) showed strong geographical differences. Mudge (1981) stated that it was rather surprising that wing bones were useful in detecting regional variations of lead exposure because of their long-term lead retention and the widespread movements of the birds. However, it was possible to identify current exposure of the ducks by analyzing the lead residues in the liver. Additionally, it was reported that in two collection areas where background levels of lead from non-pellet origins were high (industrial lead discharge, mining tailing, lead runoff from natural deposits), the environmental load was reflected in the levels in the wing bones. From those results, it would appear impossible to link lead concentrations in wing bones to the source of contamination unless other tissues (liver, gizzard) were also analyzed and some information on local sources of contamination was available.

Temporal changes of lead residues in wing bones have been documented. Immature Mallards and Pintails collected from three hunting refuges in the U.S. as the hunting season progressed had lead levels in wing bones which increase from October to January (White and Stendell, 1977). The median lead level in Mallard wing bones collected in October was 1.6 ppm dry weight compared to 9.0 ppm in January. For the same period, median lead levels in wing bones of Pintails increased from 0.5 to 20.0 ppm. Those increments in median lead residue levels as the hunting season progressed corresponded to the percentage of samples with greater than 20 ppm lead. This percentage of Mallard wing bones increased from 15% in October to 27% in January. Similarly, wing bones of Pintails with greater than 20 ppm lead residues increased from 0% in October to 4.6% in January. Analyses of lead in wing bones of Black Ducks from the third collection area only showed small increases in median lead levels (3.5 to 4.2 ppm) and in the percentage of wing bones with greater than 20 ppm lead residue (11% to 15%) from October to December (White and Stendell, 1977). The above evidence demonstrates that the timing of collection must be considered when wing bones are procured for lead analysis.

To properly interpret the significance of lead residues in wild waterfowl populations, it is imperative that one has an understanding of factors that can affect the accumulation of the contaminant in tissues.

Differences in wing bone lead content as a function of age have been reported. One would have expected this occurrence since bone lead levels reflect the history of exposure to this contaminant. Stendell et al. (1979) reported higher lead residues (means, median and percentage of wing bones with over 20 ppm lead) in adult Mallards, Pintails and Lesser Scaup compared to the immatures. In addition, only 1.6% of the adult Mallards in their nationwide survey had trace amounts (< 0.5 ppm) of lead in their wing bones compared to 15.4% of the immature Mallards. Similar trends were found in the other species surveyed. In the British survey, Mudge (1981) did not find significant differences in mean wing bone lead concentrations between adult and immature ducks. However, for most species, there was a higher proportion of adult wing bones with greater than 20 ppm lead than the immatures. Mudge (1981) also reported that the similar lead levels in juvenile and adult wing bones may be attributed to young ducks being exposed to the contaminant relatively early in life. Wing bones of adult Lesser Scaup found dying from acute lead poisoning were reported to contain lower lead residues than those of immatures (Anderson, 1975). It was suggested that the younger birds were able to deposit lead at a faster rate than adults or that the immature birds were more resistant to the effects of accumulating lead.

The sex of the bird does not appear to play a major role in the accumulation of lead residues except during the breeding season. Finley et al. (1976a) reported higher wing bone lead levels (112.27 ± 44.27 ppm, dry weight) in female Mallards dosed with one No. 4 lead shot compared to male

Mallards (10.22 ± 1.46 ppm). The experiment was conducted with breeding ducks and the difference in accumulation of lead in bone was related to medullary bone formation before and during the egg laying cycle because lead accumulation in bone is enhanced by calcium mobilization and the female birds have an increased calcium requirement during egg-laying. In accordance, Finley and Dieter (1978) found that laying female Mallards given one lead shot accumulated higher lead residues (180 ppm) in wing bones compared to non-laying Mallards (25 ppm). The residue data of waterfowl collected during fall and winter surveys have not shown significant sex differences in accumulation of lead in wing bones (Anderson, 1975; White and Stendell, 1977). Szefer and Falandysz (1986) found no significant sex-related differences in the concentrations of metals (iron, zinc, manganese, copper, cadmium), with the exception of lead, which was higher in males of Greater Scaup overwintering in Gdansk Bay. Interestingly, Wiemeyer et al. (1986) found an inverse correlation (r = -0.909, p = 0.012, N = 6) in lead concentrations between bone (humeri) and feathers (secondary wing feathers) in breeding female Common Ravens (Corvus corax); bone concentrations decreased as those in feathers increased.

Diet has been reported to be important in the susceptibility of waterfowl to lead and in the magnitude of lead absorption in bones. Jordan and Bellrose (1950) dosed adult wild Mallards with one No. 6 lead shot and provided one group of ducks with a diet of mixed grains. A similarly treated group was given mixed grains with aquatic coontail plants as a supplement. No mortality occurred in the second group of ducks while 70% of the first group died. Other experimental investigations have demonstrated that ducks fed exclusively on rice or corn diets are more susceptible to lead toxicity than waterfowl feeding on more varied and nutritious diets (Stendell et al., 1979). Furthermore, adult Mallards provided corn or rice diets and given one to five lead shot pellets accumulated about 10 times more lead than similarly dosed Mallards fed a more nutritious pelletized commercial duck ration.

Other factors which can influence the level of lead in bones have been considered. Mudge (1983) discussed how the shooting intensity of an area, geographical location, habitat type and the time of year can have an impact on pellet ingestion in waterfowl. It can be accepted that these interrelated factors would also have a bearing on lead levels found in bones and other tissues in collected specimens. This is appreciated in light of evidence demonstrating significant correlations between the frequency of occurrence of lead shot in gizzards to median lead levels in wing bones (White and Stendell, 1977).

Information on the accumulation of chemicals in wing bones, other than lead, is sparse. Di Giulio and Scanlon (1984) reported the concentrations of lead and zinc in ulnar bone of 15 species of waterfowl from Chesapeake Bay (see Table 5). They attempted to use this part of the wing bone for measuring cadmium and copper, but the levels in the samples were below the limits of detection (0.10 and 0.5 ppm, respectively). Stoneburner et al. (1980) were successful in detecting cadmium, mercury and selenium in the ulnar bones of Sooty Terns, Sterna fuscata (see Table 5). Struger et al. (1987) presented levels of calcium, phosphorus, zinc, cadmium and mercury in addition to lead levels in humeri of adult and prefledged Herring Gulls (Larus argentatus) from the Canadian Great Lakes. They found that cadmium levels, although low, were markedly higher in immature birds than in adults suggesting a transfer of cadmium to the kidneys with age.

In their preliminary study on using chemical elements to differentiate the natal areas of waterfowl, Devine and Peterle (1968) reported that activities of aluminum, chlorine, calcium, manganese and sodium were readily measurable by neutron activation analyses in wing bones of Mallard, Black Duck and Blue-winged Teal. However, other elements which may be present were masked by the sodium and chlorine spectra. Hall and Fisher (1985) measured levels of arsenic, tin, selenium, manganese, cadmium, chromium, copper and nickel (all of which are contained in lead shot) in 6 species of waterfowl with and without the presence of lead shot in the gizzard. Metal levels were found to be higher in individuals with ingested lead shot.

Some workers have reported the use of leg bones for measuring toxic metals. Howarth et al. (1981) detected cadmium, lead and zinc in the tibia of adult Crested Terns, Sterna bergii, from two colonies in Australia. In another study, Howarth et al. (1982) found higher cadmium levels (1.01 ppm, wet weight) in tibia of terns following harbour dredging and ocean dumping activities compared to samples collected prior to these operations (0.59 ppm). The bone concentrations of lead (0.43 to 0.52 ppm) and zinc (123.71 to 151.27 ppm), however, did not differ significantly in these birds. Chemical analyses of tibia or entire skeleton of nine New Zealand bird species showed fluorine levels ranging from 143 to 8050 ppm, dry weight (Stewart et al., 1974). These were believed to represent background levels of fluorine in these species. Turner et al. (1978) measured the fluorine and lead levels in bones of five estuarine bird species from seven areas in New Zealand and reported no regional differences in levels of these residues. The levels of lead, cadmium, mercury, silver, cobalt, chromium, copper, nickel and zinc were measured in leg bones (femur, tibiotarsus and fibula) of Common Terns, *Sterna hirundo*, from Hamilton Harbour in Ontario and Long Island Sound in New York (Connors et al., 1975). All metals were detected in bones of birds from the two colonies. A summary of studies using bones, other than wing bones, for residue analysis is found in Table 6.

5.0 WING FEATHERS

The study of feather chemistry has taken two very different directions: (1) to obtain quantitative information on the mineral content of feathers as a method of determining the geographical origin (natal or molting areas) of birds; and (2) to use the feather as a vehicle for measuring metal residues. These investigations are discussed together here since both employ similar principles and techniques for monitoring the chemical pattern of this keratinized tissue.

The pioneering work on measuring feather elemental content was first used to demonstrate geographical variations in Ruffed Grouse, *Bonasa umbellus*, in New Hampshire (Campbell, 1953; Campbell and McCullough, 1953; Grant, 1953; all cited in Parrish et al., 1983). Subsequent work on measuring chemical elements in feathers as a technique for diagnosing natal areas was conducted on waterfowl and raptorial species (Table 9).

Endogenous incorporation of elements into feathers is assumed to be restricted to the time of formation, since keratinization of feathers results in loss of vascular and nervous connections (Voitkevich, 1966). Thereby, the elemental content in the feather should reflect the chemistry of the particular environment where it was developed. This, of course, is a simplified and straightforward view of the flow of minerals through the environmental complex. Yet, it is generally believed that the assortment of minerals in feathers should bear some relationship to the occurrence of elements in the nutrient chain (Hanson and Jones, 1968). Hence, minerals that are incorporated into keratin of feathers formed on the molting areas may be used as biological tracers for determining geographical origin (Hanson and Jones, 1974).

Based on this axiom, primary flight feathers of waterfowl have been studied extensively (Table 9). Primary feathers of these birds are molted annually and simultaneously. Since the birds are flightless and have restricted movements until new feathers are formed, it is postulated that the feather mineral patterns should bear some relation to the chemical composition of the environment where they are grown (i.e. natal areas of juveniles and breeding areas of adult geese).

The most comprehensive information has been derived from the studies on feather mineral patterns of Blue, Snow and Ross' Geese (*Chen caerulescens*, *C. rossii*) (Hanson and Jones, 1976). The determination of the absolute and relative levels of twelve elements (aluminum, boron, calcium, copper, iron, magnesium, manganese, phosphorus, potassium, silicon, sodium, zinc) in primary feathers of over 3000 birds showed some success for ascertaining the breeding (or molting) grounds of geese populations of known and unknown origins (see Chapters 4 and 5 of Hanson and Jones, 1976). The significance of the mineral content in feathers, however, cannot be adequately interpreted without consideration of the life history of the birds, including the ranges and movements of the populations in the breeding and molting areas. Banding data and information on the individual goose colonies from which the samples were derived assisted in pinpointing the origins of known populations for which mineral patterns were determined. Other factors which were considered included the molt pattern of these birds, the local geology and mineral composition of soil and food items (Hanson and Jones, 1976). Furthermore, the limits and variability of the levels of minerals in feathers, and the mechanisms which can affect the mineral content of feathers, were also deliberated. While the results of those studies (Table 9) are encouraging and the technique shows potential for diagnosing the origins of waterfowl populations, many problems remain to be clarified. The variability of feather mineral patterns within the population and between feathers of a bird will certainly limit the applicability of the technique. Those are discussed below.

5.1.1 DIFFERENCES ASSOCIATED WITH SPECIES

Kelsall (1970a) measured the mineral levels in primary, secondary and tertiary wing feathers of Lesser Scaup and Mallards from the prairie region, White-fronted Geese (Anser albifrons) from the western Arctic and Black

Ducks from the Atlantic provinces. The elemental composition of the feathers in this preliminary study showed some species differences but the small sample sizes and methods of subsampling for analysis does not justify detailed speculation on these findings. Furthermore, Hanson and Jones (1976) criticized the study because the samples were from such wide geographical areas that the data may have little meaning. In addition to differences in diet, they suggested that the amino acid composition of feather keratin of the individual waterfowl species was likely a major factor in the observed species-related differences in mineral content of feathers.

If feather mineral patterns reflect the chemical composition of the environment, then one may infer that two bird species provided with the same experimental diet would show similar feather mineral profiles. Kelsall and Calaprice (1972), however, found that captive Lesser Scaup, Mallard and Black Ducks maintained on similar commercially prepared rations could still be chemically separated by species by measuring zinc, iron, calcium, potassium, phosphorus and copper levels in primary feathers. Other elements (silicon, sodium, manganese, magnesium and sulfur) were not reported to be discriminating factors. While those ducks were kept on the same diet and housed in a common outdoor enclosure, the opportunity existed for the birds to supplement their prepared rations with natural food items during the period of feather growth. Hanson and Jones (1976) also argued that differences in the components of the diet actually ingested and absorbed by the digestive tract would further contribute to this separation of species by feather chemistry.

In a later study, Kelsall et al. (1975b) reported no clear distinctions in the feather chemistry of captive Black Ducks and Mallards. However, captive Lesser Scaup maintained under similar experimental conditons showed significant differences in levels of minerals in primary feathers compared with Mallard and Black Ducks. The classification of known and unknown waterfowl species on the basis of the chemical content of their feathers by discriminant function analyses showed that 81.1% of known birds and only 63.5% of unknown birds were assigned correctly. It was suggested that in wild birds, the variability in mineral content of feathers would be even greater since those birds would be foraging on more abundant and different varieties of natural food items. This would enhance the discriminating power of this technique for classifying waterfowl populations.

5.1.2 DIFFERENCES ASSOCIATED WITH AGE

Marked chemical differences were reported between primary feathers of captive Black Duck, Mallard and Lesser Scaup when the birds were 1, 2 and 3 years old (Kelsall et al., 1975b). In fact, the discrimination and assignment of the birds by year-class using the feather mineral profiles was found to be the most accurate (88.9% of known birds and 78.5% of unknown birds). The variability in feather chemistry between juvenile (year 1) and adult (years 2 and 3) birds was attributed to differential physiology. The significant differences between adult year classes was speculatively attributed to the greater abundance of natural foods available to the birds during the time of feather formation in year 2.

Hanson and Jones (1968) found many clear distinctions in the feather mineral profile of Snow Geese populations from Cape Churchill, Manitoba and Southampton Island, Northwest Territories, but a close similarity in mineral values for adult and immature birds from each colony was reported. Only phosphorus levels differed significantly, being higher in adult geese. Those workers believed that the time spent on the breeding grounds (1-2 months) by adults prior to the molt allows these birds to achieve a mineral balance in their bodies which is similar to immature individuals. Conversely, Kelsall _et_ _al_. (1975a) found significant differences in the levels of sodium, calcium, copper, iron, magnesium, manganese, zinc and silicon in primary feathers of young-of-the-year and adult Snow Geese captured in the MacKenzie Delta. These differences were reported to have resulted from differences in feeding habits and chemical requirements for growth.

In their detailed study of Snow Geese populations, Hanson and Jones (1976) reported higher values for potassium, iron, silicon and aluminum in primaries of adult birds from Baffin Island than immature birds. This relationship did not hold for geese from Cape Henrietta Maria, Ontario. Feathers of immature geese from this colony had significantly higher values of iron, aluminum and silicon than adults. The age factor, as indicated by contradictory information, suggests that feathers of adult and immature specimens should be considered separately when determining the geographical origins of waterfowl populations - especially in cases where chemical variability in feathers due to age could mask intercolony differences.

5.1.3 DIFFERENCES ASSOCIATED WITH SEX

Variable differences in feather mineral profiles between male and female waterfowl (within the same age and species) have been documented. Captive male and female Lesser Scaup were distinguishable by their feather chemistry, but no significant separation by sex was revealed for Mallard and Black Ducks (Kelsall and Calaprice, 1972; Kelsall et al., 1975b). The chemical differences between sexes were not strong, as was evident by the accuracy of classification by discriminant function analyses of known (69.4% correct) and unknown (67.9% correct) birds. Yet, it is known that male and female individuals of some duck species molt and regrow their flight feathers in different areas and at different times from each other (Palmer, 1976). Therefore, the small differences observed in experimental studies with captive birds may be magnified in wild specimens.

Adult female Ross' Geese from the Northwest Territories and California had higher levels of copper and sodium in primary feathers than adult male geese (Hanson and Jones, 1974; 1976). Hormones, presumably estrogen, were suggested to have an indirect effect on the incorporation of these minerals into the feather keratin of females. Sex differences in the levels of potassium, sodium, copper, iron, magnesium and silicon were found in primaries of young and adult Snow Geese collected in the Northwest Territories (Kelsall et al., 1975a). Young female Snow Geese that were hatched, raised and maintained in Alberta had higher levels of magnesium and zinc in growing primaries than male geese.

The differences in feather chemistry attributed to sex of ducks and geese within populations may interfere with the sensitivity of this technique for identifying the origins of these birds. This question was examined by Kelsall and Burton (1979) using primary feathers of wild and captive Snow Geese. From these mineral profiles, it was reported that the classification of sex by discriminant function analysis was not significantly greater than by chance alone. The percentage of female and male geese correctly classified was 54.7 and 51.8, respectively. Despite the statistically significant differences in feather mineral patterns between sexes (as well as age), the effect on population diagnosis as a whole was reported to be minor. The accuracy of the classification process would be increased given adequate sample sizes (40 or more specimens) and chemically diverse populations or subpopulations of geese.

5.1.4 DIFFERENCES ASSOCIATED WITH FEATHER GROWTH AND MOLT

Freshly molted primary feathers of geese (grown in the previous year) are not recommended as ideal samples for chemical analysis because their mineral content may not be representative of the population occupying the colony of collection (Hanson and Jones, 1976). This cautionary measure should be taken unless the history of the bird which underwent the molt is indicated to be similar in the previous year to other birds in the colony where the molted feather was obtained. Hanson and Jones (1976) compared molted feathers found near Cape Henrietta Maria, Ontario, to growing primaries of geese from this colony. The former feathers contained significantly higher levels of calcium, magnesium, phosphorus, iron, copper and aluminum, and lower levels of sodium and boron, than the growing feathers. In addition, molted feathers showed little resemblance in mineral patterns to feathers of banded geese from the same colony shot during the fall.

Primaries of Snow Geese are molted in July, grown anew in August and carried until the following July. The feather samples which best represent the mineral profile of a population are recently-grown, fully-developed primary feathers (Hanson and Jones, 1976). Significant differences in levels of minerals (calcium, sodium, zinc, copper) were found among partially-grown primaries of Snow Geese collected in July and fully-developed primaries of birds collected in September. Kelsall and Pannekoek (1976) reported that whole primaries of captive Snow Geese contain more calcium, magnesium, manganese, iron and silicon, and less sodium and potassium, than one-half to two-thirds grown feathers. The higher mineral content of fully-formed feathers may be a result of continued incorporation of elements until growth is complete. The decrease in sodium and potassium was speculated to be from leaching of these more water soluble chemicals. Kelsall and Burton (1979) examined the differences in mineral pattern of feathers within the feather-years of captive Snow Geese, and also concluded that partially-grown feathers should not be used in diagnosing populations.

The possibility of chemical changes occuring within feathers during the time it is on the bird is a strong one. Kelsall and Burton (1979) analyzed the mineral content in primaries of captive Snow Geese in eight time periods and 4 separate feather years (August-October-June, 1972-73; October-June, 1973-74; October-June, 1974-75; October-June, 1975-76). As previously stated, the partially-grown feathers (August samples), provided poor representations of the population. However, comparison of fully-developed feathers (October and June samples) also showed mean chemical differences. The differences in zinc levels were the most consistent, being higher in June compared with October. In those captive birds, the observed chemical changes occurring within feathers during the year is a real phenomenon which contributes to within-group variability. Most of the changes (except zinc) involved appear to be inconsistent from year to year and remain to be explained (Kelsall and Burton, 1979). Processes such as sunlight and leaching are likely to have an effect on some chemicals incorporated in feathers during the time they are on the bird (Kelsall and Burton, 1977). Bortolotti and Barlow (1985), however, found no appreciable difference in the chemical profile of back feathers from the same molt sampled from Bald Eagles at the start and finish of an 11-month interval.

5.1.5 INTERNAL AND EXTERNAL INFLUENCES AFFECTING FEATHER MINERAL PATTERNS

The complex roles of how mineral levels in the ecosystem and metabolic regulation of minerals can affect the elemental concentrations (aluminum, boron, calcium, iron, magnesium, manganese, phosphorus, potassium, silicon, sodium, zinc) in primary feathers of geese populations have been thoroughly reviewed (Chapter 7 of Hanson and Jones, 1976) and will not be discussed here in detail. The importance of interelemental relationships was raised when it was found that increased levels of calcium in feathers tended to be accompanied by higher levels of other elements (except potassium) in Blue, Snow and Ross' Geese. Numerous other interelemental correlations in feathers were also found. Similarly, Kelsall and Burton (1979) reported strong positive correlations for calcium-manganese, manganese-iron and iron-titanium levels. Thirty additional correlations between chemical elements were also noted.

The metabolic controls of mineral homeostasis are believed to be exerting some influence on the elemental concentrations of feathers. Hanson and Jones (1976) concluded from their data (Chapter 8) that macroelement levels (calcium, magnesium, potassium, sodium) in primary feathers are first a reflection of the total complex of environmental minerals and secondly, related to metabolic regulation of absorption of individual elements. The exception is phosphorus, which is affected by physiological regulations - primarily absorption - to a greater extent than other macroelements. Concentrations of trace elements, such as aluminum, boron, copper, iron, manganese and silicon, appeared to be more related to the levels in the environment and, to a lesser degree, to metabolic regulation. Zinc was the exception, and was found to be the most closely regulated mineral studied (primarily through absorption). Due to the numerous elemental interactions within and between various components of the environment, and the various processes of metabolic controls within the body, it is not surprising that the actual levels of minerals in feathers are not wholly related to environmental levels.

Although findings discussed in the previous subsections emphasized mineral pattern variations, the final judgement of this technique is its sensitivity and accuracy in discriminating the breeding or molting areas of bird populations of known and unknown origins. It should be stressed, at this time, that similarities in mineral profiles have been repeatedly demonstrated with geese of known origin collected from the same area in the same year, as well as with banded geese of unknown origin collected from the same area in the same year. Birds of both examples are believed to be of the same groups (colony or subcolony) of geese that associate together on the same breeding or molting grounds and utilize similar food resources. Numerous other examples of the use of feather mineral patterns as biogeochemical indicators for geese are provided by Hanson and Jones (1976; Chapters 4 and 5).

The accuracy of discrimination of this technique was also tested by Kelsall and Burton (1977; 1979). They reported that when provided with adequate sample sizes (n = 40 or more per population) for generating multivariate discriminant functions, the power of the analysis was sufficent to override differences between geographical populations and sex among the wild geese that were examined. In addition, this classification and discriminant analysis was not greatly affected by the differences associated with sex, year class, age and feather-year among their captive geese. However, their diagnosis was biased towards a correct classification because only two populations were compared. With three populations, discrimination was much less accurate (40.3 to 53% unknowns classified correctly) compared to two (76.8 to 82.3% unknowns classified correctly). Yet, for their objectives and the species used for study, the results of these investigations are encouraging and show potential for diagnosing goose populations.

5.2.1 THE USE OF FEATHERS FOR MONITORING ENVIRONMENTAL RESIDUES

A large body of data on contaminant levels in avian plumage has been assembled over the last 20 years. The quality of this information, as well as the sampling objectives and strategies, vary greatly among these studies (see Table 10). Three routes of metal uptake in the feather can be distinguished: (1) uptake through the food and incorporation during feather growth, (2) contamination through preening - heavy metals present in secretion products of salt- and/or preen glands contaminate the feathers - and (3) outside contamination through direct contact with the environment (water, air, mud, etc.) (Goede and de Bruin, 1986). Feathers have been used as an indicator of residue levels for endangered species (Carlisle, 1979; Ohlendorf et al., 1985; Wiemeyer et al., 1986).

The initial success of using bird feathers for monitoring environmental residues was in documenting the historical trends of mercury levels in feathers of Swedish avifauna (reviewed by Johnels et al., 1979). Analyses of terrestrial bird feathers from museum specimens showed the original mercury loads to be low (about 100 ng/g) during the period between 1840 and 1940. An enormous rise (10 to 20 times earlier levels) in feather mercury concentrations was found from the 1940s to the mid-1960s (Berg et al., 1966). Although those workers reported considerable variations in mercury concentrations between different parts of feathers as well as different feather types within and between bird species, the data still clearly showed the temporal trend in mercury contamination in the birds. This increase in mercury accumulation in feathers coincided with the introduction of methylmercury compounds as seed dressing used in agricultural industry. Support for the suggestion that methylmercury in seed dressing agents was chiefly responsible for the sudden increase in mercury concentrations in feathers was derived from several findings. Feathers of both seed-eating birds (Ring-necked Pheasant, *Phasianus colchicus*; Partridge, *Perdix perdix*) and predatory birds (Peregrine Falcon, *Falco peregrinus*; Eagle-owl, *Bubo bubo*; White-tailed Eagle, *Haliaetus albicilla*; Hen Harrier, *Circus cyaneus*) inhabiting agricultural regions showed this temporal trend in mercury levels. Birds such as the Willow Grouse (*Lagopus lagopus*), collected during 1847 to 1950 in mountainous areas remote from agriculture and chemical industries contained background levels in their feathers (28 to 130 ng/g) and no indication of a change in mercury contamination over time. In addition, feathers of pheasants from Denmark, where methylmercury seed dressings were not widely employed, contained low levels of mercury (66 to 82 ng/g) (Berg *et al*., 1966).

Following the prohibition on the use of alkylmercury compounds in agriculture in 1966 in Sweden, a decrease in mercury levels in bird feathers was evident (Johnels and Westermark, 1969; Westermark *et al*., 1975). Goshawks (*Accipiter gentilis*) collected from 1967 to 1969 had feather mercury levels which were significantly lower (3.1 to 5.1 ug/g) than those from 1940 to 1966 (20 ug/g). In most cases, mercury concentrations in feathers of Goshawks obtained after 1966 were of similar magnitude as feathers collected before 1940. Other terrestrial bird species also showed a decline in mercury levels in feathers after the ban on alkylmercury use in 1966. The mercury concentrations in Eagle-owls collected from 1966 to 1974 and Marsh Harriers (*Circus aeruginosus*) collected from 1966 to 1976 decreased after the ban and have remained low (below 3 ug/g) (Johnels *et al*., 1979).

Analysis of the Osprey (*Pandion haliaetus*) and Great-crested Grebe (*Podiceps cristatus*) provided a historical account of mercury contamination in the aquatic ecosystem of Sweden (Johnels *et al*., 1968; Johnels and Westermark, 1969). During the 1900s, a progressive rise in the mercury content of the aquatic environment was reported and substantiated by the levels in feathers of the two fish-eating species. Feather mercury concentrations in those birds were generally higher than those of terrestrial species collected between 1840 and 1940. Prior to 1900, the average level in feathers of Osprey and grebe was around 4000 ng/g. This probable background level increased gradually (to approximately 15,000 ng/g) during the period between 1940 and 1966. The source of mercury contamination was believed to be from the chlor-alkali industry which was introduced in Sweden about 1900. Other industrial developments (burning of raw materials, mercurial uses in medicine, leather industry and chemical manufacturing industries) may also have contributed substantial quantities of mercury into the aquatic systems.

5.2.2 TEMPORAL VARIATION IN FEATHER RESIDUE LEVELS

In addition to the above studies on mercury pollution in Swedish birds, other investigators have employed feather residue levels for establishing temporal trends. Spronk and Hartog (1970) analyzed the mercury content of the inner side of the calamus of flight feathers of the Buzzard (Buteo buteo) from the Netherlands and concluded that higher levels (n = 9; 2 to 23 ug/g) were found in individuals collected after 1950 compared to earlier periods (n = 5; 1 to 11 ug/g). Secondary feathers of Common Guillemots (Uria aalge) collected from 1906 to 1925 contained low mean mercury concentrations (2.7 ppm) relative to those examined in 1969 (5.4 ppm) which was related to the increased level of mercury pollution in the Baltic Sea (Jensen et al., 1972). This is in agreement with the data of Somer and Appelquist (1974) and Appelquist et al. (1985) which showed a significant increase in the mercury content in feathers of Common Guillemots and Black Guillemots (Cepphus grylle) from the Swedish Baltic Archipelago in the late sixties relative to values found during the earlier part of the century and a subsequent decline in mercury content of feathers from Baltic Common Guillemots in the period since 1969. Trace element concentrations (arsenic, cadmium, chromium, copper, mercury, nickel, lead, zinc) in feathers of a California Condor (Gymnogyps californianus) that died in 1938 were generally similar to those found in recent (1980) samples; minor exceptions being that cadmium was detected in the 1938 sample but not in recent samples, and arsenic was higher in the 1938 sample than in recent ones (Wiemeyer et al., 1986).

Feathers of nestling Ospreys collected in 1972 and 1978 from three sites in Finland showed significant decreases in mercury levels of 27 to 55 percent between the years (Hakkinen and Hasanen, 1980). Likewise, Odsjo and Olsson (1975; cited in Broo and Odsjo, 1981) reported decreasing mercury levels in feathers of Eagle-owls in Sweden from 1965 to 1975. Broo and Odsjo (1981) found a similar trend for mercury levels in feathers of Eagle-owls from inland populations collected in southwestern Sweden between 1967 and 1972, with concentrations in the latter years approaching background levels (2020 ng/g) or levels found in feathers of Eagle-owl specimens obtained between 1829 and 1933. The mercury concentrations in feathers of coastal populations of Eagle-owls were significantly higher (6510 ng/g) than their congeners of inland populations (3200 ng/g) and showed no decrease. Lindberg and Odsjo (1983) compared the variation in mercury levels of feathers of Peregrine Falcons (Falco peregrinus) collected between 1834 and 1977 in Sweden. No significant variation was found during the period from 1971 to 1977. However, comparison of their data with the earlier results of Berg et al. (1966) which demonstrated high mercury levels in feathers collected between 1943 and 1966, showed mercury levels had decreased significantly after 1966. The mercury content of feathers of Goshawks collected prior to 1947 was also low (2.2 ppm), while specimens collected between 1948 and 1965 had values as high as 80 ppm (Edelstam et al., 1969; cited in Doi et al., 1984). Solonen and Lodenius (1984) found mercury concentrations in feathers of Finnish Sparrowhawks (Accipiter nisus) also rose significantly between the 1950s and 1960s compared with earlier samples (1900-1950), followed by a significant decrease in the 1970s.

A study of mercury levels in feathers of birds collected from the Shiranui Sea in Japan from 1955 to 1980 showed a peak in mercury levels in feathers between 1970 and 1977 (Doi et al., 1984). This peak in feather mercury concentrations did not coincide with the height of mercury discharge from local industries which occurred between 1958 and 1964. The shortage of samples from the period 1955 to 1967 was believed to be chiefly responsible for the lack of correlation.

Analysis of bird feathers from museum specimens appears to be a practical method for tracing the past environmental pollution by mercury. Temporal changes in feather levels of mercury was clearly documented in some cases because of gross contamination of the habitat and food resources of these birds. This was evident in studies where a 10 to 20 fold difference in mercury concentrations existed between feathers collected before and after the introduction of mercury for agricultural and industrial use. Such large differences will likely override sampling and analytical variations, as well as the inherent variations found in different feather types and feather parts (Berg *et al*., 1966). In addition, these temporal changes may be magnified by the method of collection of these museum specimens. Wallin (1984) stated that samples obtained after the introduction of mercury were probably biased towards highly contaminated individuals because poisoned birds are more conspicuous due to abnormal behavior or are found dead. Therefore, they are more likely to be collected. Furthermore, as investigators began to study the pesticide problem, a more random selection of specimens for analysis was obtained. This could have contributed to the marked decrease observed in the mean concentrations of mercury.

5.2.3 GEOGRAPHICAL VARIATION IN FEATHER RESIDUE LEVELS

Residue concentrations in feathers of birds obtained from various sites have often been employed for establishing geographical trends of metal contamination. Tejning (1967a) demonstrated that feathers of Ring-necked Pheasants from Sweden sampled in areas sowed with methyl and ethyl-mercury treated seed grains contained higher levels (0.90 to 79.4 ng/g) of mercury than those from areas without treatment. No mercury was detected in the plumage of pheasants from the latter areas. These findings unequivocally demonstrated that mercury in tissues of seed-eating birds originated from alkymercurials used for seed dressing.

Johnels and Westermark (1969) reported that all primary feathers of an Osprey nestling hatched in Sweden contained about 20,000 ng/g of mercury. Primary feathers of an adult Osprey returning to Sweden from the wintering grounds in Africa had a very different pattern of mercury levels. Primaries grown in Sweden (Nos. 4 and 8) had similar levels to those of the nestling, while the other primary feathers which were formed in the wintering quarters contained much lower levels of mercury (5000 ng/g or less). This information is consistent with the characteristic molt pattern of Ospreys and indicated that much lower mercury contamination was occurring in the birds' wintering quarters compared to their breeding sites in Sweden.

Five to seven fold differences in mercury concentrations in mantle feathers of Osprey nestlings were reported among sampling sites in Finland (Hakkinen and Hasanen, 1980). In Lapland and in southwestern areas, the feathers averaged 3.4 to 4.5 ppm of mercury which were considered as natural background levels. Feathers of birds collected from mercury-polluted rivers and lakes of Finland contained 18.3 to 24.7 ppm of mercury.

White-tailed Eagle feathers collected in northern Sweden were found to contain lower mercury concentrations (about 1.0 ppm) relative to those from the more polluted locales in the Archipelago of Stockholm (25 to 51 ppm) (Jensen et al., 1972). The analyses of mercury in feathers of Peregrine Falcons from northern (17.6 ppm) and southern (9.95 ppm) Sweden showed similar regional variations in contamination levels (Lindberg and Odsjo, 1983). It was reported that falcons from the south prey mainly on terrestrial bird species whereas falcons from northern regions consume mostly aquatic bird species. This point is supported by feather mercury data indicating the aquatic ecosystem in Sweden to be generally more contaminated by mercury than the terrestrial ecosystem. A statistically significant difference was found in mean mercury levels in feathers of the inland population of Eagle-owls (3200 ng/g) and the coastal population (6510 ng/g) in Sweden (Broo and Odsjo, 1981). This contrast in mercury contamination between populations was attributed to differences in food choice or feeding from different food webs.

In addition to these Scandinavian investigations, there have been other reports of regional variations in mercury residues in feathers. Anderlini et al. (1972) observed that the concentrations of mercury in tail feathers of Ashy Petrels, Oceanodroma homochroa, from California (4.86 ppm) were higher than those found in Wilson's Petrels, Oceanites oceanicus, (1.89 to 2.44 ppm) and Snow Petrels, Pagodroma nivea, (1.77 ppm) from Antarctica. The difference was attributed to the increased exposure to industrial development at the former site. In the Lake Erie region, Hoffman and Curnow (1973; 1979) found higher mercury levels in primary feathers of island nesting herons and egrets compared to those nesting in a woodlot. This difference was believed to reflect the levels of contamination in local feeding sites. Doi et al. (1984) compared mercury residues in feathers of omnivorous terrestrial birds from Japan to those from China and Korea and found greater levels in the first location (1.5 ppm) relative to the latter two sites (0.2 ppm). Comparison of the mean mercury, cadmium and selenium levels in tail feathers of Sooty Terns from Florida and Hawaii demonstrated greater contamination by all three metals in birds from the Florida colony. This finding was believed to reflect the metal contamination of the marine food chains of the two nesting sites. In contrast, Howarth et al. (1981) did not find significant differences in the concentrations of cadmium, copper, lead or zinc in primary feathers of Crested Terns breeding near industrialized and non-industrialized areas. Struger et al. (1987), however, found higher lead levels in primary feathers of Herring Gulls from an industrial site (Hamilton Harbour) in western Lake Ontario than in birds from the other Canadian Great Lakes. Cadmium and mercury levels (except mercury in feathers of prefledged Herring Gulls) did not reflect the same geographical pattern.

Getz et al. (1977) compared the lead concentrations in primary feathers of four song bird species from rural and urban areas and reported significantly higher levels in the urban populations. Similarly, Grue et al. (1984; 1986) found higher lead levels in plumage of Barn Swallows

(Hirundo rustica) and Starlings (Sturnus vulgaris) from highway colonies than from rural control areas. Dmowski and Karolewski (1979) reported higher lead and cadmium levels in plumage of four passerine species from the area of a zinc mill compared with a steelworks and a control forest, and Sawicka-Kapusta et al. (1986) found higher levels of cadmium and lead in remiges and rectrices of three species of tits from polluted areas than from control sites whereas levels of zinc, copper and iron did not differ significantly. No variations in lead, cadmium, nickel and zinc concentrations in feathers of Wild Turkeys (Meleagris gallopava) from two physiographic regions in Virginia were detected (Scanlon et al., 1979a). These levels were considered as natural background concentrations from uncontaminated areas. Lead levels in primary feathers of woodcocks from 32 U.S. states showed large differences according to the state of collection (Scanlon et al., 1979b). Yet, due to the migratory nature of this species, the state of sampling may not correspond to the area where their feathers were grown.

Caution should be exercised when interpreting metal residues in feathers sampled from two or more sites. Geographical variations in feather residue levels have often been attributed to contamination of food resources of the birds in the various locations. The contributions of minerals from the local geology have rarely been considered in those investigations. Scanlon et al. (1979a) have reported that the low levels of lead, nickel, cadmium and zinc in Wild Turkey feathers reflected those found in soils of the region. Furthermore, studies of the mineral composition of waterfowl feathers for defining natal areas have emphasized the input of elements from the nutrient chain - tracing back to their geological origins (Hanson and

Jones, 1976).

5.2.4 SPECIES VARIATION IN FEATHER RESIDUE LEVELS

In their study of mercury contamination in feathers of eleven Swedish bird species, Berg et al. (1966) found considerable differences in mercury levels among species even prior to the period (1840 to 1940) when alkyl-mercurial compounds were introduced. Mercury in feathers of birds of prey during this time frame ranged from 340 to 15,500 ng/g compared with 20 to 930 ng/g in seed-eating species. In addition, Johnels et al. (1979) reported that during the 19th century, birds feeding on aquatic animals generally contained higher mercury levels than those consuming terrestrial organisms. When alkylmercury was employed in agriculture (1940 to 1966), similar species differences in contamination were observed. Solonen and Lodenius (1984) found the level of mercury in the Sparrowhawk to be generally higher than in many other species. The differential accumulation of mercury among those species can be attributed to differences in the position of the birds in food chains and the general contamination of the food webs (aquatic or terrestial) from which their foods were acquired.

Lindberg (1984) reported lower mercury levels in Gyrfalcon (Falco rusticolus) feathers (1.72 ppm) relative to those of Peregrine Falcons (17.6 ppm) from northern Sweden. Food choice was the factor found chiefly responsible for the interspecific difference in mercury levels. Resident Gyrfalcons consumed mainly local herbivorous species such as grouse and ptarmigan, whereas the highly migratory Peregrine Falcon consumed a high proportion of insectivorous and omnivorous prey such as waders. Mercury concentrations in these common prey species support this postulation (Lindberg and Odsjo, 1983).

Other workers have also related differences in mercury concentrations in feathers to the food habits of the birds. Clay *et al*. (1979) found the levels of mercury in primary feathers of Horned Grebe (*Podiceps auritus*), Bufflehead (*Bucephala albeola*), Lesser Scaup, Ruddy Duck (*Oxyura jamaicensis*) and American Coot (*Fulica americana*) to correlate with the percentage of animal matter in the diet. A relationship between trophic levels and primary feather mercury concentrations of Great Blue Herons (*Ardea herodias*), Black-crowned Night Herons (*Nycticorax nycticorax*) and Great Egrets (*Casmerodius albus*) was established for four populations in the Lake Erie marsh ecosystem (Hoffman and Curnow, 1979). Similarly, Hutton (1981) attributed the large interspecific differences of zinc and mercury levels between feathers of Oystercatchers (*Harmatopus ostralegus*), Herring Gulls and Great Skuas (*Catharacta skua*) to differences in feeding behavior and to the extent of habitat contamination.

The variations in levels of copper, iron, mercury, manganese and zinc in feathers of twelve species of wild and captive birds from Japan were ascribed to "some special biological or biochemical mechanism" (Doi and Fukuyama, 1983). A later study reported a relationship between feeding habits and mercury content of feathers (Doi *et al*., 1984). Classification of the birds into five groups showed fish-eating seabirds to contain the highest mercury load (7.1 ppm), followed by omnivorous waterfowl (5.5 ppm), predatory birds (3.6 ppm), omnivorous terrestrial birds (1.5 ppm) and herbivorous waterfowl (0.9 ppm). It should be pointed out that those birds were collected from the Shiranui Sea region, where industrial discharge of methylmercury into surrounding waters had resulted in contamination of the local aquatic environment. The order of decreasing mercury contents in the various groups may have been different if they had been obtained from an unpolluted area.

Gochfeld (1980) analyzed the mercury content in breast feathers of four fish-eating seabirds endemic to the Humboldt Current of Peru. It was reported that the low variation within species and the similar mean values indicate that geographical variables (different exposures to chemical residues) and ecological variables (different trophic levels) play greater roles than taxonomic factors (variation among the species) in determining the mercury levels in these birds. In a study of three upland game bird species, Parker (1985) suggested that the deposition of nickel and copper into plumage during growth may be a process universally common to phylogenetically related species therefore supporting the use of closely related species as comparable bioindicator species over wide geographical areas. Osborn et al. (1979) compared the distribution of mercury, cadmium and zinc in tissues, including primary feathers, of Puffins (Fratercula arctica), Fulmars (Fulmaris glacialis) and Manx Shearwaters (Puffinus puffinus) and commented on the validity of interspecific comparisons. The detected differences in toxic metal residue data among the species likely reflect either differences in the level of exposure or differences in metal metabolism. Furthermore, in view of their findings showing seasonal variability in essential and toxic metal concentrations in tissues, such interspecific comparisons should be performed with caution. Additionally, Hanson and Jones (1976) stated that besides the factor of diet, variations in feather mineral profiles can probably be related to species-related differences in the amino acid composition which make up the feather keratin.

5.2.5 VARIATION IN FEATHER RESIDUE LEVELS ACCORDING TO AGE, SEX AND CONDITION OF THE BIRD

Reports of differences in feather residue levels between age classes - lower levels of contaminants in juvenile birds compared with adults - have often attributed this phenomenon to the duration of exposure. Hoffman and Curnow (1979) found higher mercury levels in primary feathers of adult herons and egrets compared with nestlings of the same population. Since the adult diet was similar to that of the young bird, the shorter exposure time of the latter age class was likely responsible for the differences in mercury levels. Correspondingly, Broo and Odsjo (1981) determined that young Eagle-owls from Sweden contained lower levels of mercury in the plumage (2300 ng/g) than adult birds (3200 ng/g.). Feathers of young Peregrine Falcons from Finland also had mean mercury levels which were 2.8 times lower than adults (Lindberg *et al*., 1983).

If feathers reflect contamination in the area where they were grown, it may not be surprising that age plays a role in the residue levels in that juvenile and adult birds may molt at different times and in different areas. The pattern of mercury contamination in primary feathers of adult and juvenile Ospreys collected in Sweden was found to differ (Johnels and Westermark, 1969). This was related to the molt characteristics of the species and to mercury contamination of the location where each feather was formed. Some primaries of adult and all primaries of juvenile Ospreys which were developed in Sweden contained approximately 20,000 ng/g of mercury. However, primaries Nos. 1 to 3 and 5 to 7 of the adult specimen, which were formed in the less polluted wintering grounds in Africa, had about 5000 ng/g of mercury or less.

In an investigation of metal contamination of feathers of the Knot (*Calidris canutus*), Bar-tailed Godwit (*Limosa lapponica*) and Icelandic Redshank (*Tringa totanus*) from the Dutch Wadden Sea, the workers reported that adult birds molt and form all their feathers in this area whereas juvenile birds molt only their small feathers and retain their flight feathers which are formed in their northern breeding ground (Goede and de Bruin, 1984). Consequently, flight feathers of adults should reflect the chemistry of the wintering ground while flight feathers of juveniles reflect the chemistry of the breeding ground. Those findings demonstrate that the age and molt pattern of the species as well as information on their migratory tendencies must be taken into account when interpreting feather residue levels.

In a study on mercury levels in Bonaparte's Gulls (*Larus philadelphia*), Braune and Gaskin (1987) found differences in mercury concentrations among age groups reflected in the primary wing feathers, increasing from juveniles to second-year birds to adults. As the molt progressed, however, mercury concentrations decreased across the primary feather sequence from the first innermost to the tenth outermost feather as levels converged toward a minimum asymptotic mercury level. No significant between-sex differences were detected in mercury concentrations in primary feathers of juvenile and second-year Bonaparte's Gulls, but adult males had significantly higher mercury levels than females in the first 5 primary feathers suggesting that the females may have reduced their body burden of mercury through egg-laying prior to molt.

Few age differences were found in levels of metals in feathers of upland game birds surveyed in the United States. The concentrations of lead, cadmium and nickel in Wild Turkeys from Virginia did not vary according to age, but feathers of adults (98.89 ppm) contained higher zinc levels compared with immature birds (79.36 ppm) (Scanlon et al., 1979a). Lead concentrations in feathers of Ruffed Grouse from Virginia (Scanlon et al., 1980) and in woodcocks from 32 states in the eastern United States (Scanlon et al., 1979b) were not significantly different according to age groups. In addition, no sex differences were found in the three surveys. The metal levels in feathers of those birds were not considered excessive and may represent background levels of these metals. However, no apparent trends in metal levels with respect to age and sex were also reported in birds from contaminated areas. Ranta et al. (1978) reported that the lack of trends in copper and nickel in feathers of ducks with respect to age and sex can be ascribed to external absorption of these metals onto the feather surface.

Lindberg and Odsjo (1983) separated male and female Peregrine Falcon feathers for mercury analyses because this species displays reversed sexual size dimorphism which could affect the choice of food items, and therefore, mercury exposure. However, no significant differences in mean mercury levels between male (6.35±2.35(SD) ppm) and female (8.90±5.19 ppm) birds were revealed. In their study of metal contamination in Long-tailed Ducks (Clangula hyemalis), Szefer and Falandysz (1983) also found no differences between the concentrations of cadmium, cobalt, copper, lead, manganese, nickel and zinc in feathers of male and female birds. In a later study on Greater Scaup, Szefer and Falandysz (1987) also found no difference between the concentration of iron in addition to the previously listed 7 metals in feathers of male and female birds. In addition, adult Black Ducks fed a diet with 3.0 ppm mercury for 28 weeks showed no differential accumulation of the metal in feathers between the sexes (Finley and Stendell, 1978).

No consistent trends in feather mercury content according to age or sex were detected in their study of the history of mercury contamination in Swedish birds (Berg et al., 1966). This may be due to limited numbers of birds from the same period. As previously mentioned, the condition of the collected birds may have played a role in the large temporal trend in mercury contamination that was observed (see section 5.2.2 and Wallin, 1984). Other studies have also reported variations in feather metal content as a function of the condition of the bird. Frank et al. (1983) found that emaciated (sick, poisoned or diseased) Common Loons (Gavia immer) contained higher mercury levels in back and belly feathers compared with apparently healthy specimens. In contrast to these findings, Szefer and Falandysz

(1983) reported that feathers of oiled Long-tailed Ducks had lower concentrations of iron, zinc, manganese, lead and cadmium, but higher levels of copper and nickel compared to birds taken from fishing nets. No reasons were advanced for these differences.

5.2.6 DIFFERENCES IN RESIDUE CONTENT BETWEEN FEATHER TYPES AND WITHIN INDIVIDUAL FEATHERS

Some studies which employed feathers as a medium for chemical analyses have acknowledged that residue levels can vary between different feathers from the same bird as well as between different parts of the same feather. Yet, few workers have attempted to measure the magnitude of these variations. Furthermore, many examples can be extracted from the published record where comparisons between residue levels of different feather types are made.

During the study of temporal trends of mercury contamination in the Swedish avifauna, it was reported that variations in mercury levels by factors of 1 to 2 existed within a feather (Berg *et al*., 1966; Johnels and Westermark, 1969). The mercury content in the various portions of the shaft of a feather from an Eagle-owl ranged from 17,500 ng/g to 30,500 ng/g. Levels in different vane portions ranged from 14,100 to 29,000 ng/g (Berg *et al*., 1966). Those variations were found to be low compared with the magnitude of contamination (10 to 20 times) reported and would not seriously affect their final conclusions. In addition, those workers standardized the feather part (surface of the shaft) employed for chemical analysis. However, the residue data of different feather types obtained from museum specimens were often used for their comparisons.

In their investigations on feather mineral patterns of geese, Hanson and Jones (1976) employed only the vane portions of primary feathers because they were found to be more highly mineralized than the shaft. In addition, the basal portion of the vane was not included in the analyses because this part of the feather is formed after the bird has regained flight and therefore may not be representative of the bird's breeding or molting areas. Kelsall (1970b) studied the relative concentrations of calcium, copper, manganese and zinc in vanes and whole primary feathers of Mallard Ducks and found that vanes contained higher mean levels of calcium (350.6 and 209.7 ppm), manganese (9.60 and 5.66 ppm) and zinc (183.4 and 124.0 ppm), than whole feathers. Copper levels also seemed higher in the vanes (5.72 ppm) than the whole feathers (4.64 ppm), but the difference was not statistically significant. Work on feathers from Bald Eagles showed that concentrations on the upperside of the curve of secondary remiges were significantly lower than the underside for bromine, chlorine and sodium, and significantly higher for manganese, vanadium and calcium (Bortolotti and Barlow, 1985). That study also found that the highest concentrations of magnesium, manganese, aluminum, vanadium and calcium were found in the most distal section of the feather and progressively decreased towards the proximal end with the opposite trend true for bromine and chlorine. Kelsall (1970b) recommended the use of whole feathers for chemical analyses because the results were less variable than vane-only analyses. Furthermore, handling of feathers and the removal of vanes from the feather could introduce variability and possible contamination. Yet, if the absolute concentrations of the elements are to be determined and if the concentrations of the elements are near detection limits, analysis of vane portions would be valid because whole feathers contribute a greater weight of ash which could mask small differences in elemental levels (Kelsall, 1970b). Alternatively, because the chemical profile of the vane is more variable among feathers than that of the calamus, the vane may be more strongly influenced by environmental or physiological factors and thus may be more suitable for studies of geographic variation (Bortolotti and Barlow, 1985).

Doi and Fukuyama (1983) analyzed the metal content in the shaft and vane of primary and tail feathers of 12 bird species. Although the sample sizes were small (n = 1 to 5), it was reported that the vane portions generally contained higher concentrations of iron, manganese, mercury and zinc compared with the shaft. Copper concentrations seemed greater in the shaft than the vane of the analyzed feathers. Another recent study demonstrated that the concentrations of arsenic, cadmium, lead, mercury, selenium and zinc were consistently higher in the vane compared to the shaft of primary flight feather No. 8 of juvenile Knots (Goede and de Bruin, 1984). Braune and Gaskin (1987) also showed mercury levels to be higher in the vane of primary feathers of Bonaparte's Gulls than in the rachis or quill. Dmowski _et_ _al_. (1984) showed that, for various feathers of a kestrel (_Falco_ _tinnunculus_), lead tends to accumulate least in the quill and most in the feather top. As well, correlations were found to exist between the pigmentation pattern of kestrel feathers and the concentration of lead.

The findings of Kelsall _et_ _al_. (1975b) demonstrated consistent and statistically significant chemical variation between individual primary feathers of Snow Geese. Although their study showed that feathers of left and right wings from the same bird exhibited bilateral symmetry, differences in potassium, calcium and iron levels were detected among primary feathers (Nos. 2 to 7) according to number. They concluded that such variability can be surmounted by consistently using a particular primary feather. Primary feather Nos. 4 and 5 were recommended because they were the most highly mineralized. Bortolotti and Barlow (1985) also found variability in the chemical profiles of secondary remiges along the wing in Bald Eagles. In their work with Canada Geese, Edwards and Smith (1984) found that as primary feather number increased, the concentrations of sodium and potassium increased and the levels of calcium, boron, iron, phosphorus and zinc tended to decrease. In general, the feather mineral profiles of feather Nos. 1, 2, 3, 8, 9 and 10 demonstrated significant differences from other feather numbers, while feather Nos. 3, 4, 5, 6 and 7 were not markedly different. They suggested that the standardization of the choice of feather, such as primary feather Nos. 5, 6 and 7 would help to remove this primary number effect.

Buhler and Norheim (1981) studied the extent of variation in mercury levels in primary, secondary and tail feathers of Sparrowhawks. The mercury concentrations ranged from 2 to 20 ug/g in the different feathers. Those levels were reported to reflect the molting pattern and it was suggested that the position of the feather within the plumage used for analyses must be known when investigating the degree of contamination in bird populations.

Ellenberg and Dietrich (1981) found small differences (up to 3 fold) in lead and cadmium levels in similar length primary feathers of Goshawks. However, large variations in concentrations of these metals were observed among primary, secondary, tail, back and down feathers of a single bird. Differential factors of up to 25 for lead and 8 for cadmium were found in concentrations of these metals among the feather types. These differences in residue levels showed a temporal trend which was related to the timing of molt and growth of the feathers, and contamination of prey species during this period. Feathers grown early or later in the season contained lower levels of metals than those formed between May and July. Doi and Fukuyama (1983) reported large differences in copper, iron, manganese, mercury and zinc concentrations among flight feathers, tail feathers, wing coverts, dorsal feathers and abdominal feathers. Unfortunately, the significance of these variations were not discussed by those investigators. Braune and Gaskin (1987) found that the abdominal and down feathers of Bonaparte's Gulls had significantly higher mercury concentrations than the dorsal, tail, and wing primary, secondary and covert feathers suggesting that growth of the former two feather types was initiated early in the molt process when the mercury body burden was still relatively high. Bortolotti and Barlow (1985) found chemical profiles of the body feathers (back, breast, head) to be similar to each other but different from the remiges and rectrices. The wing and tail feathers had lower concentrations of bromine, sodium and chlorine, and higher levels of manganese, aluminum and calcium. It should be noted, however, that these authors were comparing levels among entire body feathers and only the tips of wing and tail feathers.

Backstrom (1969) observed by autoradiography that mercury is concentrated in the plumage of Japanese Quail (Coturnix coturnix japonica), with a continuous uptake during feather development and no accumulation after keratinization. That finding indicated that mercury deposition is dependent on the level in the bloodstream when the feather is formed. The time required for full development of a new feather differs among feather types and among species but generally takes about 3 to 5 weeks (Palmer, 1972). This could explain the variation in residue levels observed within individual feathers and between feather types, since one would not expect a constant blood residue level to occur throughout the period of feather growth.

5.2.7 EXTERNAL CONTAMINATION AND STABILITY OF RESIDUES IN FEATHERS

Although most studies assumed that mineral levels found in feathers reflect their concentrations in the assimilated food of the bird during the time of feather growth, few workers have examined the possibility that exogenous sources can also influence the residue levels in the plumage. Berg *et al*. (1966) reported three cases where aberrant levels of mercury were found in feather samples. Two Partridge feathers and one Willow Grouse feather obtained in the 1800s contained unexpectedly high levels of mercury (1100 to 5800 ng/g). Those samples were believed to have been contaminated by mercurials after the specimens were collected. In their study of Snow Geese, Kelsall *et al*. (1975a) also reported that abnormally high elemental concentrations are periodically encountered when analyzing individual samples. It was postulated that inadequate washing practices may have resulted in contamination of these samples.

Ranta and co-workers (1978) reported geographical variations in copper and nickel levels in primaries of Mallard and Black Ducks sampled near a smelter in Sudbury, Ontario, compared with those from a northern Saskatchewan population. The metal levels in feathers also showed a gradual decrease with increasing distance from the smelter site. No variation in zinc concentrations was detected. They explained that external adsorption with subsequent binding by physicochemical processes were responsible for the higher copper and nickel levels in primaries of ducks collected in areas with known particulate fallout. This was supported by comparable levels of the metals in soil and vegetation samples in those locations. Additionally, their findings were corroborated by the study of Rose and Parker (1982) which reported that the elevated copper, nickel and iron levels in plumage of Ruffed Grouse collected near smelters in Sudbury were of exogenous origin. Newly grown feathers of grouse from the contaminated site were found not to differ in metal content compared to newly grown feathers of birds from an uncontaminated area. However, premolt feathers - plumage that has been on the bird for one feather year - of birds collected near the smelter contained metal concentration 7 to 20 times higher than premolt feathers of birds sampled from the control site. Further evidence of physicochemical surface absorption of metals on feathers was provided by the results of their in vitro experiment. The data demonstrated a linear time-related uptake of metals onto grouse feathers which were exposed to atmospheric conditions at the smelter site. No measurable or minimal gains for copper, nickel and iron levels were detected in feathers exposed to the atmosphere at a location 100 km away from the smelter. The findings signify that exogenous influence can greatly affect the metal concentration of feathers. Under the conditions of those two studies, feather metal loads showed greater variability as a result of external contamination than from endogenous incorporation.

The effects of exposure to "artificial seawater" on the elemental (calcium, copper, iron, magnesium, potassium, zinc) concentrations in goose feathers have been investigated (Hanson and Jones, 1976). Following a 48 hour exposure period to a solution containing 0.04% calcium, 0.127% magnesium, 0.38% potassium and 1.05% sodium (followed by distilled water washes), the concentrations of sodium and magnesium exhibited threefold increases, and calcium levels were elevated to twice the control values.

Findings from a recent study also suggest that feather mineral profiles can change when exposed to new and chemically different environments (Edwards and Smith, 1984), but their results differed from those of the earlier work. After exposing goose feathers to a 1% solution of calcium, magnesium, potassium, sodium and zinc salts for 48 hours, a significant increase in zinc levels, and significant decreases in aluminum, calcium, copper, iron, magnesium, manganese and sodium concentrations were found in treated feathers. No changes were seen for boron, potassium and silicon concentrations. The large increase in zinc levels (7x) led to the postulation that by ionic exchange, zinc ions are capable of stripping away absorbed ions in the feather matrix. Yet, in their investigation, feathers treated by salt-loading were still correctly assigned to their proper populations. This indicates that the "residual" feather mineral profiles still reflected the birds' natal areas despite the fact that the feather chemistry can be modified when exposed to chemically different environments. However, if the absolute concentration of an element - rather than the relative levels of a spectrum of elements - is being analyzed, the dynamic nature of ion exchange in the feather matrix can greatly compromise the use of feather material for monitoring purposes. This would depend on the stability of the element following incorporation.

A recent publication has contributed insight into the potential usefulness and shortcomings of using feathers for monitoring metal residues by treating feathers to various manipulations. Goede and de Bruin (1984) surveyed the mercury, selenium, arsenic, zinc, lead and cadmium levels in feather parts of Knots and Bar-tailed Godwits from the Dutch Wadden Sea. Those workers analyzed the shaft and vane portions of primary flight feather No. 8 from recently-arrived birds (in August) and resident birds (in October) for the purpose of detecting changes in feather metal concentrations in the two groups over time. Additionally, the possibility of external contamination from exposure to seawater and sediment or from uropygial gland secretions was explored.

The results of the above study showed that the vane and shaft portion (or even whole feather) were satisfactory media for mercury analysis. No significant changes in mercury levels occurred in the vane and shaft of birds collected in August and October. That is, the concentrations in feathers reflected the levels in the birds during feather formation in their northern breeding grounds and exposure to mercury in the wintering ranges did not contribute to the feather chemistry. Exposure to suspended sediments in seawater also did not affect the mercury levels in the feather parts. Furthermore, the input of mercury residues from the preen gland was considered negligible since the levels in the secretions were found to be low or non-detectable. Therefore, external contamination as tested by the above conditions did not significantly affect mercury levels in the feather parts.

The usefulness of monitoring other metallic residues in feather parts is less certain. Zinc levels in vane and shaft portions did not show any changes with time, and external contamination by exposure to seawater was not evident. However, the uropygial gland appeared to be a source of zinc contamination on feathers because detectable levels were found in the secretions (Goede and de Bruin, 1984). This may explain the increase in zinc concentrations found in feathers of geese during the "feather year" as reported by Kelsall and Burton (1979).

The feather shaft appears to be promising for monitoring arsenic, selenium and lead exposure in birds, if it is sampled soon after the molt (Goede and de Bruin, 1984). Residues in vane portions showed increases with time which would represent exposure after feather formation or exogenous surface absorption. External contamination from uropygial gland secretions is also possible since all three metals were detected. The results of cadmium analyses were equivocal since this metal was found in only a few feather samples.

Another factor which can introduce variability into feather analysis is the stability of metallic ions in this matrix. An examination of the stability of mercury binding in feathers of guillemots was recently attempted (Appelquist _et al_., 1984). The effects of ultraviolet light, temperature (-20°C; 20°C; and 100°C) and weathering (rain, wind and sun exposure) on mercury levels in the shaft of primary feather Nos. 1 to 10 were investigated. They reported that even after 8 months of exposure to the various conditions, the loss of mercury was less than 10% relative to "reference feathers". Untreated primary feather Nos. 1, 5 and 10 were employed as the references. Their results showed individual variations in mercury concentration among primaries of the same bird (as shown graphically: about 3500 to 4600 ng/g in a Black Guillemot and 2400 to 3200 ng/g in a Common Guillemot). In addition, differences in mercury levels between corresponding primaries on the left and right wing of the same bird were evident. The limited sample size (n = 5) and the inherent variation found in mercury concentrations between primary feathers - even untreated feathers - do not allow for a proper exploration of the magnitude of change afforded by the various manipulations. Furthermore, the observed loss of weight found in some treated feathers (heated to 100°C) caused an actual increase in mercury levels which emphasizes that without proper controls, other than the "reference feathers", the extent of mercury loss cannot be accurately investigated.

Hanson and Jones (1976) investigated the effects of wash time on the elemental composition of feathers. In the first experiment, no significant differences in mean levels of calcium, copper, iron, magnesium, sodium and zinc were indicated between feathers washed for 1 hour and 4 hours (with rinses and fresh water added in each hour). However, after washing for 8 hours, there appeared to be appreciable loss of sodium, and possibly calcium and potassium. This was made evident by chemical analysis of the wash water. Yet, it is unclear if the minerals detected in the wash water were removed from the external surface of the feather or were leached from the internal matrix of the feather.

To test the possibility of leaching of arsenic, mercury, selenium and zinc from feathers, Goede and de Bruin (1984) washed parts of primary wing feathers of adult Knots in simulated sea water (3.5% KCl solution) for up to 24 hours. Their data showed that mercury residues are stable in all parts of the feather (the vane, vaned portion of the shaft and the vaneless portion of the shaft) with no indication of leaching. Similarly, arsenic was not leached from the feather parts. Selenium and zinc could be partly washed out of the vanes, but the concentrations of these two metals appeared stable in the shaft.

The stability of feather minerals was recently investigated using several approaches by Edwards and Smith (1984). The effects of wash solutions and preparation techniques on the concentrations of aluminum, boron, calcium, copper, iron, magnesium, phosphorus, potassium, silicon, sodium and zinc in primary feathers of Canada Geese were studied. In the first experiment, washing feathers in a non-ionic surfactant solution (1% Triton X-100) for 6 hours resulted in reduced levels of 9 of 12 elements compared to those washed in deionized water. Significant reductions in the concentrations of calcium and magnesium occurred. In the second test, feathers washed in a mild acid solution (0.5N HCl) caused a 30% reduction in the total mineral content relative to feathers washed in deionized water. The concentrations of calcium, magnesium, manganese, potassium and zinc were significantly lower in the acid-washed feathers. The third experiment explored the physical aspect of washing feathers in deionized water for 5 to 6 hours, using either a reciprocating shaker or ultrasonic bath. Chemical analyses showed greater levels of aluminium and iron in feathers washed by the latter method which was attributed to possible contamination by these ions from the glass beakers used in the experiment. However, the summations of the conductivities of the wash water from the two methods of agitation were found to be similar. The results of those experiments indicate that standardization of sample preparation procedures should be a major consideration when analyzing feathers. Yet, the question of how "clean" the samples should be prepared for analyses remains unresolved. That is, if the minerals removed during cleaning are desorbed from the external surface of the feather (i.e. exogenous contamination), stripped from the feather (i.e. internal deposition), or a combination of the two processes.

5.2.8 THE ROLE OF MOLT IN FEATHER RESIDUE LEVELS

Experimentally, decreases in body levels of mercury have been shown to be linked to molting. Less work, however, has been conducted with other metals. Growing feathers are known to be important routes of excretion of mercury in domestic fowl (Tejning, 1967a) and Japanese Quail (Backstrom, 1969). The mercury is initially deposited in internal organs and thereafter, gradually transported via the blood to the keratinized structures. Stickel et al. (1977) reported that Mallard drakes eliminated one-half of the accumulated mercury load from their bodies in about 12 weeks. It was noted that no detectable decline occurred during the first 8 weeks. However, a major reduction in mercury was observed between the ninth to twelfth week which was correlated with the growth of new feathers during this time. Braune and Gaskin (1987) found that the newly grown feathers of adult Bonaparte's Gulls contained 93% of the body burden of mercury just after molt due to the redistribution of mercury from the tissues to the feathers.

The pattern and time sequence of molt can greatly influence the residue levels of collected feather specimens. This was briefly deliberated in earlier sections. The example showing variation in mercury levels in primary feathers of Ospreys from Sweden clearly illustrated this point (Johnels and Westermark, 1969). Buhler and Norheim (1981) also reported similar findings for Sparrowhawks from Norway. A relationship was established between the molt characteristics of individual primary, secondary and tail feathers and their mercury content. Dmowski and Karolewski (1979) showed that amounts of lead and cadmium in feathers of passerines also varied over the years, decreasing with the post-nuptial molt. Goede and de Voogt (1985) found that the lead levels in vanes of newly grown primary feathers (No. 8) of adult Knots were 3 to 4 times higher than those of juvenile Knots. Adult birds molt and grow new primaries in their wintering grounds in the Dutch Wadden Sea and these elevated lead concentrations were indicative of contamination in this area. Juvenile Knots, however, retain primary feathers grown in their remote breeding grounds while wintering in the Wadden Sea. The small increase found in lead levels in feathers of juveniles was reported to be an indication of external contamination. In another study, similar differences were reported for arsenic levels in vanes of primary feathers (No. 8) of adult and juvenile Dunlins, Calidris alpina (Goede and de Bruin, 1985). This evidence further supports the postulation that these vane residue levels in adult birds reflect the internal deposition of metals during the period of feather formation since these waders display the molt pattern seen in Knots. A study on residue levels in feathers of 6 species of waterfowl with and without lead shot in the gizzard led Hall and Fisher (1985) to suggest that the stage of molt had to be taken into consideration before feathers could be used to predict lead ingestion. The shedding and replacement of feathers in most birds is an annual event which follows a characteristic pattern for the group of birds or for the species (see Palmer, 1972). The effect of a sequential or synchronous molt pattern on the distribution of mercury across the primary feather sequence has been demonstrated for several species of marine birds (Braune, 1987). The results of the above surveys demonstrate the importance of obtaining information on the molt cycles of the species being monitored.

Studies using captive birds provided with controlled diets during the molt period further emphasize the role this process has on the feather residue concentration. Peregrine Falcon nestlings collected from the wild in Finland and Scotland contained higher mean mercury levels in their first plumage compared with their second (Lindberg and Odsjo, 1983). The initial levels were reported to be 4.45 ppm and 1.40 ppm in Finnish and Scottish birds, respectively. However, after being maintained on low-contaminated food for one year and following their molt, the concentrations in their second plumage decreased significantly to 0.56 ppm in birds taken from Finland and 0.65 ppm in birds collected from Scotland. This marked reduction in feather residue levels was also evident in an adult Peregrine Falcon captured in Scotland and maintained on a controlled diet for one year (Lindberg and Mearns, 1982). Mercury levels in the first plumage (2.6 ppm in a primary feather and 2.8 ppm in a tail feather) were considerably higher than those in the new plumage of the second year (1.0 ppm in a secondary feather and 0.46 ppm in a tail feather). These decreases in feather residues are believed to reflect an overall decline in total body burden of mercury in the birds, which can be correlated with the lower mercury content in the food during the period preceding the molt.

Lindberg and Odsjo (1983) employed the Sequential Feather Analysis technique proposed by Gochfeld (1980) in their investigation of mercury residues in primary and tail feathers of Peregrine Falcons from southern Sweden. By knowing the position of the feather in the molt pattern of migratory bird species, one can plot residue levels against the molting sequence and relate these data to residue intake at different times or in different areas. Although their sample sizes were small, the data suggest that lower levels of mercury were found in feathers molted later on in the season (July - August) compared to those shed earlier. This was believed to be related to a shift from adult to juvenile prey as the season progressed, with the latter prey containing less mercury residues. Honda et al. (1986b) also showed mercury concentrations to decrease from the first primary feathers to those molted later in Black-eared Kites as did Braune and Gaskin (1987) in adult Bonaparte's Gulls. Similarly, Furness et al. (1986) and Braune (1987) showed, for a variety of seabirds, that feathers replaced early in the molting sequence have higher levels of mercury than those molted later. It is acknowledged that conclusions derived from these calculations are approximate since the growth rate of a feather is dependent on its position in the molt sequence, its length, and possibly, on the nutritional state of the bird. In addition, even if one presumes that feather residue levels reflect the blood level at the time of feather formation, it should be realized that the blood level in itself is a reflection of both past exposure and current mobilization (Gochfeld, 1980).

In cases where the degree of contamination is being investigated, it is clear that the position and timing of molt of the analyzed feather must be considered. The above studies showed that by examining the mercury content and the molt of each individual feather, particularly primaries, one may establish geographical or temporal trends using such data. Yet, the usefulness and precision of the Sequential Feather Analysis technique requires further assessment by more extensive sampling and by employing various species with different molt characteristics. Alternatively, Furness et al. (1986) have suggested the use of body feathers as most representative of the whole-bird mercury content since variation in mercury levels is least in samples of body feathers compared with primary wing feathers.

5.2.9 FEATHER - BREAST MUSCLE RESIDUE RELATIONSHIPS

Attempts have often been made to correlate the residue levels in feathers with those in breast muscle. If a constant relationship can be established, then the residue concentrations in the feather material can be used to predict those in the edible portion of the bird. Berg et al. (1966) divided the feather (surface of shaft) mercury levels of pheasants by 7 to convert to breast muscle concentrations. Similarly, Johnels and Westermark (1969) reported a ratio of the mercury content in feather to breast muscle was 7 to 1. The species used to determine this ratio and the mercury concentrations in the tissues were not given in this study.

Vermeer and Armstrong (1972a) reported that the mean mercury level in whole primary feathers (1.29 ppm) were approximately 12 times higher than that in the breast muscle (0.11 ppm) of adult Pintails from Alberta and a correlation ($r = 0.6436$) was found between the mercury load of the two tissues. Primaries of immature ducks (1.40 ppm) were reported to contain 22 times the mean mercury level found in breast muscles (0.07 ppm). However, no correlation was detected between residue levels in the feather and muscle of immature Pintails. Statistically significant correlations between mercury levels in primary feathers and breast muscles of immature dabbling ducks ($r = 0.814$) and adult dabbling ducks ($r = 0.450$) collected in the spring were reported (Driver and Derksen, 1980). No correlations were found for adult dabblers captured in the fall, or adult and immature diving ducks.

Huckabee et al.(1972) examined the correlations between mercury residues in back feathers and breast muscles of 48 pheasants from Idaho. It was reported that 91% of feather samples contained mercury when it was detected in the corresponding muscle sample. Seven feather samples had detectable levels of mercury (greater than 0.008 ppm) when one was found in the breast muscle. Six pheasants contained no detectable mercury residues in the feather or breast samples.

Whitehead (1973) determined that the mean mercury level in primary feathers (the distal 2.5 cm portion of the feather) was 0.94 ppm or 24 times greater than levels in the breast muscle (0.033 ppm) of five adult Bobwhite Quail (Colinus virginianus). The individual ratios ranged from 11 to 39. A breast muscle : mantle feather ratio of 1:10 was found for mercury residues in Osprey nestlings from a moderately polluted area in Finland (Hakkinen and Hasanen, 1980). Yet, the mercury concentrations in feathers and breast muscles of Osprey nestlings from an uncontaminated region were similar. The findings of these studies demonstrate that the relationship between mercury load in feather parts and breast muscle varies among species and with age, and is affected by the type and level of contamination. Particularly for species which undergo a sequential molt, information on the position of the feathers and their molting sequence are essential in considering feathers as indicators of mercury in birds (Honda et al., 1986b). With the information that is available, it appears that the analysis of mercury residues in feather material would have limited usefulness for predicting the mercury levels in body tissues. Obviously, more studies on the variables that can affect the bioaccumulation of mercury - and other residues - in feathers relative to other tissues are needed.

6.0 SUMMARY AND CONCLUSIONS

In this report, we have reviewed the literature on the use of wing parts for surveying toxic chemical residues. The findings showed that attempts have been made to employ whole defeathered wings, wing muscles, wing bones and feathers as media for chemical analysis. Despite inherent sampling and analytical variations, and differences in monitoring objectives and strategies, some success has been documented. Future studies should be less concerned with recording the occurrence of chemical residues in these structures and more concerned with exploring the significance of the chemical load to the bird population and to the overall environment (i.e. temporal and geographical trends).

Attesting to one of the basic considerations of surveying environmental residues, the studies reviewed have most frequently reported the ease of collection of these parts. In addition, the focus of attention has centered on persistent environmental residues (i.e. whole defeathered wings: organochlorines; wing muscles: mercury; wing bones: lead from spent shot; wing feathers: mercury). Indeed with the exception of a small handful of recent publications, few workers have attempted to explore the possibility of exploiting these structures for surveying other contaminants (organochlorines other than DDT residues and PCBs; metals other than mercury) and determining their signficance to the health of the birds and their consumers.

Besides the studies of DDT residues in whole defeathered wings and lead residues in wing bones, little attention has been focused on the relationship of contaminants in the wing parts to other body tissues. That is, no quantitative information on the metabolism and pharmacokinetics of the chemical residues was obtained prior to the use of wing parts for monitoring purposes.

Other specific conclusions drawn from this review are as follows:

Whole Defeathered Wings

(1) The consistent sampling methodology, the consistency of the migration pattern of ducks (i.e. flyways) and the rapid assimilation of organochlorine residues by these birds have allowed for the collection of quantitative information on the temporal and geographical trends of these persistent compounds in the U.S.

(2) Single monitoring efforts using whole defeathered wings are of limited use other than establishing baseline information.

(3) The precision of surveying residues in wings has been reported to vary according to collection site and is dependent on the number of wings sampled. The biases inherent in the system of wing collection in Canada (see Appendix B) and the distribution of ducks on the breeding grounds (see Bellrose, 1976) may limit the use of wings for establishing geographical trends in Canada. Sampling problems may result from the mixing of ducks from different flyways during migration, and by the inability to collect sufficient samples from specific sites due to the method of submission of waterfowl parts.

Wing muscles

(4) To our knowledge, no residues, other than mercury and DDE, have been measured in this wing part.

(5) The relationship between residues in wing muscles and breast muscles has not been shown to be sufficiently consistent to be of practical use at this stage.

Wing bones

(6) Few studies have analyzed residues, other than lead, in wing bones.

(7) The lead content in wing bones is an indication of absorbed lead from all sources and no differentiation can be made.

(8) The main value of wing bone residue data is for establishing species and regional differences in lead exposure in the birds. However, the type of exposure (acute or chronic) can not be defined unless other tissues were analyzed and information on point sources of pollution was obtained.

Wing Feathers

(9) While much work has been conducted on mercury residues in feathers, there is less information for other metals.

(10) Not enough attention has been focused on mercury and other metal residues in feathers in relation to other body tissues or the overall body burden.

(11) Only recently have studies begun to emphasize the importance of the molting process, external contamination and metal stability in keratin on feather residue results.

(12) The significance of the possible variations in mineral levels of feathers, as stressed in studies of the natal and breeding grounds of waterfowl (see Hanson and Jones, 1976), has often been overlooked or ignored when using feathers for monitoring purposes.

(13) The work conducted to date is rather unsystematic and requires standardization. The use of feather types and feather parts, the timing of collection of feathers, as well as sample preparation and washing procedures should be standardized. Otherwise, the precision of the data and the usefulness of the information as a basis for comparison will be compromised.

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Table 1: Relationships of Total DDT Residues in Whole Defeathered Wings and Body Tissues of Mallard and Lesser Scaup (from Dindal and Peterle (1968)).

Correlation Coefficients (r)

Tissue	Mallard	Lesser Scaup
Wing	1.00	1.00
Breast skin	0.73	0.82
Kidney	0.61	0.76
Breast muscle	0.68	0.78
Uropygial gland	0.55	0.69
Adrenal gland	0.63	0.82
Pancreas	0.48	0.69
Brain	0.66	0.66
Gonads	0.27	0.62
Liver	0.18	0.50
Thyroid	0.32	0.37
Breast feathers	0.31	0.12

Table 2: Summary of the U.S. Fish and Wildlife Service Residue Surveys Using Whole Defeathered Wings of Mallard and Black Ducks.

DATE	LOCATION	AGE	SEX	N	RESIDUES	MAJOR FINDINGS	REFERENCE
1964-	New York Pennsylvania	Adult and immature	Not indicated*	36 pools of 25 wings per pool	DDT + DDD DDE dieldrin	- Adults of both species had higher DDE levels than immatures. - No significant differences in residue levels were found between the two states.	Heath and Prouty, 1967
1965-1966 1966-1967	Nationwide (48 states)	Adult and immature	Not indicated*	Approx. 12,000 wings with 25 wings per pool. (485 pools)	DDT DDD DDE dieldrin heptachlor epoxide lindane	- DDE was the predominant residue in every state with high levels in wings from New Jersey, Alabama, Massachusetts, Connecticut, Rhode Island, New York, Pennsylvania, California and Utah. - Organochlorine residues were generally highest in wings from the Atlantic and Pacific Flyways and lowest in wings from the Central Flyway. - Dieldrin was prevalent in wings from Arkansas, Texas, Utah, California and several states in the Atlantic Flyway.	Heath, 1969
1969-1970	Nationwide (48 states)	Adult	Not indicated*	Approx. 5,200 wings with 25 wings per pool. (210 pools)	DDT DDD DDE dieldrin PCBs heptachlor epoxide Hg	- No indication of decrease in residue levels were found in comparisons with 1966 levels. - Organochlorine residues remained highest in the Atlantic and Pacific Flyways and lowest in the Central Flyway. - PCB levels were highest in the Atlantic Flyway and decreased going westward. - Hg levels were highest in Black Ducks from the Atlantic Flyway.	Heath and Hill, 1974

Table 2: Summary of the U.S. Fish and Wildlife Service Residue Surveys Using Whole Defeathered Wings of Mallard and Black Ducks (continued).

DATE	LOCATION	AGE	SEX	N	RESIDUES	MAJOR FINDINGS	REFERENCE
1972-1973	Nationwide (48 states)	Adult	Not indicated*	Approx. 5,400 wings with 25 wings per pool. (237 pools)	DDT DDD DDE dieldrin PCBs heptachlor epoxide HCB BHC lindane alpha-and gamma-chlordane	- DDE levels in wings were lower in the Atlantic and Pacific Flyways in 1972 - 1973 compared to 1969-1970 levels. - PCB levels were significantly lower in the Pacific and Central Flyways compared to 1969-1970 levels. - As in 1969-1970, DDE residues in wings were highest in the Atlantic Flyway and lowest in the Central Flyway. - Mean PCB levels were unchanged in the Atlantic Flyway compared to 1969-1970, but had increased in the Mississippi Flyway. - Ducks from Alabama had unusually high PCB levels.	White and Heath, 1976
1976-1977	Nationwide (48 states)	Adult	Not indicated*	Approx. 5,600 wings with 25 wings per pool. (227 pools)	DDT DDD DDE dieldrin PCBs heptachlor epoxide mirex endrin HCB chloradane isomers	- DDE levels in wings were unchanged compared to the 1972-1973 levels in all flyways except the Pacific, where it declined. - Dieldrin levels did not change significantly. - PCB levels declined significantly in the Atlantic Flyway but did not change in the other flyways. - Other organochlorine compounds were also detected in wing pools in low quantities.	White, 1979

Table 2: Summary of the U.S. Fish and Wildlife Service Residue Surveys Using Whole Defeathered Wings of Mallard and Black Ducks (continued).

DATE	LOCATION	AGE	SEX	N	RESIDUES	MAJOR FINDINGS	REFERENCE
1979-1980	Nationwide (48 states)	Adult	Not indicated*	5,268 wings with 25 wings per pool. (215 pools)	DDT DDD DDE dieldrin PCBs heptachlor epoxide mirex endrin HCB chlordane isomers lindane toxaphene hexachlorocyclohexane	- DDE levels were not significantly lower than the 1976-1977 levels in flyways. - DDT, DDD and dieldrin residues in duck wings have decreased in percentage occurrence in all flyways. - PCBs occurred in a larger percentage of wing pools in 1979-1980 than in 1976-1977. - Wings from Alabama and New Mexico continued to show higher DDE residue levels than those from other states.	Cain, 1981
1981-1982	Nationwide (48 states)	Adult	Not indicated*	244 pools with 25 wings per pool, and 11 pools with less than 25 wings per pool. (255 pools)	DDT DDD DDE DDMU dieldrin PCBs heptachlor epoxide mirex chlordane isomers	-DDE levels in wings declined between the 1979-80 and 1981-82 collections for Mallards but not for Black Ducks. -PCB levels in wings did not change between collections for Mallards but did decline for Black Ducks. -Mallard wings collected from the Atlantic Flyway continue to have higher levels of PCBs than those collected from other flyways. -PCB levels in Black Duck wings from the northern region of the Atlantic Flyway were higher than those in wings from the southern region.	Prouty and Bunck, 1986

* Separation of the duck wings by sex was not reported in any of the surveys.

Table 3: Summary of the Use of Whole Defeathered Wings of Woodcocks for Monitoring Environmental Residues.

DATE	LOCATION	AGE	SEX	N	RESIDUES	MAJOR FINDINGS	REFERENCE
1970	8 states (unspecified)	Not indicated	Not separated	5 pools of 25 wings per state	Total DDT mirex dieldrin PCBs	- Total DDT residues in wings from the southeastern states were significantly higher than other sampling sites. - Mirex and dieldrin residues were significantly higher in wings from Louisiana and southeastern states than other areas. - PCBs were present in all wing pools but showed no geographical differences.	Stickel _et al._, 1971
1970-1971	(11 states) Louisiana Maine Michigan New Hamphire New Jersey New York Pennsylvania Tri-state area (Georgia, North and South Carolina)	Adult	Not separated	5 pools of 25 wings per state	DDT DDD DDE mirex dieldrin PCBs	- Total DDT, PCB and dieldrin levels in wings from Georgia, North Carolina and South Carolina were significantly higher than other states. - Mirex concentrations were higher in wings from Louisiana than those from other states.	McLane _et al._, 1973

Table 3: Summary of the Use of Whole Defeathered Wings of Woodcocks for Monitoring Environmental Residues (continued).

DATE	LOCATION	AGE	SEX	N	RESIDUES	MAJOR FINDINGS	REFERENCE
1971-1972	(15 states) Connecticut Louisiana New Hampshire New Jersey New York Maine Massachusetts Michigan Minnesota Pennsylvania Tri-state area (Georgia, North and South Carolina)	Adult and immature	Not separated	5 pools of 25 wings per state	DDT DDD DDE PCBs dieldrin mirex heptachlor epoxide	- Organochlorine insecticide residues were highest in the southern states and New Jersey and lowest in the northern and midwestern states. - DDE, PCB and mirex levels were significantly lower in 1971-1972 compared to 1970-1971. - Wings of immature woodcocks contained lower mirex levels compared to adult wings.	McLane _et_ _al_., 1978

Table 3: Summary of the Use of Whole Defeathered Wings of Woodcocks for Monitoring Environmental Residues (continued).

DATE	LOCATION	AGE	SEX	N	RESIDUES	MAJOR FINDINGS	REFERENCE
1974-1975	(17 states) Connecticut Georgia Louisiana Maine Maryland Massachusetts Michigan Minnesota New Hampshire New Jersey New York North Carolina Ohio Pennsylvania South Carolina Vermont Wisconsin	Adult and immature	Not separated	5 pools of 25 wings per state	DDT DDD DDE PCBs dieldrin mirex heptachlor epoxide nonachlor	- HCB, alpha-BHC, lindane, alpha-chlordane and oxychlordane were detected in some samples. - Wings from the southern states and New Jersey continued to have higher residues than wings from other states. - PCBs, mirex and heptachlor epoxide increased significantly in 1975 compared to the 1972 survey and DDT residues showed a decline. - Adult woodcock wings had higher mirex residues than wings of immatures.	McLane _et_ _al_., 1984

Table 4: The use of wing muscle for residue analysis.

SPECIES		CHEMICAL RESIDUE	REFERENCE
Blue-winged Teal	*Anas discors*	mercury	Vermeer and Armstrong, 1972b
Common Goldeneye	*Bucephala clangula*		
Common Merganser	*Mergus merganser*		
Hooded Merganser	*Lophodytes cucullatus*		
Mallard	*Anas platyrhynchos*		
Black Duck	*Anas rubripes*	mercury	Pearce *et al*., 1976
Canvasback	*Aythya valisineria*		
Common Goldeneye	*Bucephala clangula*		
Greater Scaup	*Aythya marila*		
Green-winged Teal	*Anas crecca*		
Lesser Scaup	*Aythya affinis*		
Mallard	*Anas platyrhychos*		
Redhead	*Aythya americana*		
Ring-necked Duck	*Aythya collaris*		
Snow Goose	*Chen caerulescens atlantic*	mercury	Longcore *et al*,. 1983
Australian Shellduck	*Tadorna tadornoides*	mercury	Bacher and Norman, 1984
Australasian Shoveler	*Anas rhynchotis*		
Blue-billed Duck	*Oxyura australis*		
Freckled Duck	*Stictonetta naevosa*		
Grey Teal	*Anas gibberifrons*		
Hardhead	*Aythya australis*		
Maned Duck	*Chenonetta jubata*		
Musk Duck	*Biziura lobata*		
Pacific Black Duck	*Anas superciliosa*		
Pink-eared Duck	*Malacorhynchus membranaceus*		
Brown Pelican	*Pelecanus occidentalis*	DDE	Ohlendorf *et al*., 1985

Table 5: The Use of Wing Bones for Residue Analysis.

Chemical	Species	N		ppm, dry weight			% Samples with 20 ppm lead (dry weight)	Location (Date)	Reference
				Mean	Median	Range			
Lead	Wigeon	200		7.3	<5	<5-175.9	4.0	Britain (1979-81)	Mudge, 1983
	Gadwall	32		3.0	<5	<5-19.5	0.0		
	Teal	473		7.2	<5	<5-298.8	1.9		
	Mallard	863		26.5	<5	<5-472.9	21.9		
	Pintail	48		4.8	<5	<5-61.8	4.2		
	Shoveler	35		2.7	<5	<5-10.4	0.0		
	Pochard	67		8.0	<5	<5-64.4	7.5		
	Tufted Duck	92		4.0	<5	<5-87.4	2.2		
	Goldeneye	15		4.2	<5	<5-16.9	0.0		
Lead	Ring-necked Duck	23		24.2	16.2	1.2-77.9		Chesapeake Bay (1976-80)	Di Giulio and Scanlon, 1984
	Mallard	32		22.1	7.3	<0.5-246.8			
	Canvasback	65		7.0	4.0	<0.5-45.5			
	Black Duck	24		5.6	3.7	0.8-19.5			
	Pintail	14		10.2	2.4	<0.5-86.4			
	Gadwall	14		5.7	2.0	0.8-30.3			
	American Wigeon	17		3.7	2.6	<0.5-12.9			
	Ruddy Duck	20		10.7	3.0	<0.5-43.4			
	Bufflehead	18		12.4	1.1	<0.5-132.1			
	Greater Scaup	11		1.9	0.6	<0.5-11.8			
	Lesser Scaup	26		4.8	0.6	<0.5-91.4			
Zinc	Ring-necked Duck	23		145	145	119-182			
	Mallard	32		118	112	89-176			
	Canvasback	65		157	146	103-222			
	Black Duck	24		117	119	81-136			
	Pintail	14		140	133	106-212			
	Gadwall	14		130	129	90-172			
	American Wigeon	17		139	131	110-119			
	Ruddy Duck	20		145	143	121-183			
	Bufflehead	18		175	177	101-243			
	Greater Scaup	11		150	144	112-192			
	Lesser Scaup	26		176	166	130-253			

Table 5: The Use of Wing Bones for Residue Analysis (continued).

Chemical	Species	N		ppm, dry weight			% Samples with 20 ppm lead (dry weight)	Location (Date)	Reference
				Mean	Median	Range			
Cadmium	Sooty Tern	12		11.70 ± 2.21*				Florida (1977)	Stoneburner *et al.*, 1980
Mercury	Sooty Tern	12		0.84 ± 0.07*					
Selenium	Sooty Tern	12		5.22 ± 0.73*					*Mean ±SE (wet weight)
Lead	Canvasback	5	adult/male	18		5.3-45		Wisconsin (1976)	Fleming, 1981
		5	adult/female	5.4		0.89-13			
		5	immature/ male	0.76		<0.5-7.5			
		5	immature/ female	0.98		<0.5-74			
Lead	Canvasback	5	adult/male	11		9.70-13		Wisconsin (1977)	
		5	adult/female	7.6		1.3-45			
		5	immature/ male	0.68		<0.5-5.9			
		1	immature/ female	<0.5					
	Canvasback	5	adult/male	6.3		4.9-12		Iowa (1976)	
		5	adult/female	4.6		1.0-15			

Table 5: The Use of Wing Bones for Residue Analysis (continued).

Chemical	Species	N		ppm, dry weight Mean	 Median	 Range	% Samples with 20 ppm lead (dry weight)	Location (Date)	Reference
Lead (continued)	Canvasback	5	immature/ male	0.53		<0.5-4.2			Fleming, 1981 (continued)
		5	immature/ female	1.3		<0.5-26			
	Canvasback	5	adult/male	1.7		<0.5-21		Iowa (1977)	
		5	adult/female	3.9		<0.5-14			
		1	immature/ male	18					
		1	immature/ female	<0.5					
Lead	Snow Goose	80		8.763		0.5-92.8		Louisiana (1975-76)	West, 1977
		9		5.9		1.0-15.0		Missouri (1976)	
Lead	Canvasback	78		7.8 ± 1.0*		0.6-38.2	16	Chesapeake Bay (1975)	White *et al*., 1979 *Mean ± SE.
Lead	Mallard	118	immature/-	12.23	6.0	0.5-112	17.8	New York (1974-75)	White and Stendell, 1977
		91		7.48	3.5	0.5-47.9	9.9	New York (1974-74)	
		101		4.30	0.8	0.5-79.9	5.9	Oklahoma (1974-75)	
		221		4.23	2.5	0.5-27.2	1.8	Connecticut (1974-75)	

Table 5: The Use of Wing Bones for Residue Analysis (continued).

Chemical	Species	N		ppm, dry weight			% Samples with 20 ppm lead (dry weight)	Location (Date)	Reference
				Mean	Median	Range			
Lead (continued)	Mallard	59	immature/-	2.99	0.8	<0.5-23.1	3.4	Montana (1974-75)	White and Stendell, 1977 (continued)
		217		16.45	1.8	<0.5-3069	18.9	California (1974-75)	
		238		18.58	3.5	<0.5-3459	19.7	California (1974-75)	
		193		27.85	9.6	<0.5-2702	38.3	Oregon (1974-75)	
	Black Duck	81	immature/-	8.77	3.8	0.8-64.5	11.1	Massachusetts (1974-75)	
		46		9.65	4.6	<0.5-54.5	13.0	New Jersey (1974-75)	
	Pintail	233	immature/-	2.71	1.0	<0.5-30.3	0.9	Utah (1974-75)	
		222		6.08	1.1	<0.5-151	6.8	California (1974-75)	
		174		20.53	5.3	<0.5-214	28.2	Oregon (1974-75)	
	Canada Goose	231	immature/-	6.93	0.7	<0.5-216	8.2	Missouri (1974-75)	
Lead	Canada Goose*	61		4 ± 6**		7-389		Colorado (1978)	Szymczak and Adrian, 1978 *Lead poisioned ** Mean ± SE
Lead	Mallard	1,461	immature/-	9.9	1.1		13.2	USA nationwide (1972-73)	Stendell *et al.*, 1979
		450	adult/-	12.3	4.4		19.1		

Table 5: The Use of Wing Bones for Residue Analysis (continued).

Chemical	Species	N		ppm, dry weight			% Samples with 20 ppm lead (dry weight)	Location (Date)	Reference
				Mean	Median	Range			
Lead (continued)	Black Duck	270	immature/-	8.1	3.7		9.6		Stendell *et al.*, 1979 (continued)
		45	adult/-	7.7	4.7		8.9		
	Pintail	437	immature/-	6.2	0.7		7.1		
		151	adult/-	7.0	2.7		11.3		
	Mottled Duck	159	immature/-	40.2	15.1		43.4		
		69	adult/-	48.3	16.2		43.5		
	Canvasback	109	immature/-	7.7	0.9		7.3		
		56	adult/-	16.8	9.5		26.8		
	Redhead	95	immature/-	23.5	4.0		20.0		
		51	adult/-	25.5	9.9		35.3		
	Lesser Scaup	264	immature/-	1.9	0.7		0.4		
		103	adult/-	2.8	1.4		1.0		
Lead	Lesser Scaup*	7	immature/ male	54 ± 8**		12-95		Illinois (1972)	Anderson, 1975
		12	adult/male	23 ± 2**					*Lead poisoning
		6	immature/ female	58 ± 17**					**Mean ± SE
		2	adult/female	45 ± 18**					

Table 5: The Use of Wing Bones for Residue Analysis (continued).

Chemical	Species	N		ppm, dry weight Mean	Median	Range	% Samples with 20 ppm lead (dry weight)	Location (Date)	Reference
Lead	Greater Scaup	9	male	1.7		0.02-4.1		Gdansk Bay, Baltic Sea (1982-83, 1983-84)	Szefer and Falandysz, 1986
		5	female	0.5		0.03-1.8			
Iron	Greater Scaup	9	male	120		80-170			
		5	female	130		90-290			
Zinc	Greater Scaup	9	male	140		80-210			
		5	female	140		110-180			
Manganese	Greater Scaup	9	male	3.7		1.4-5.5			
		5	female	3.6		2.6-6.9			
Copper	Greater Scaup	9	male	1.1		0.4-3.1			
		5	female	1.5		0.4-2.1			
Cadmium	Greater Scaup	9	male	0.2		0.01-0.07			
		5	female	0.2		0.01-0.04			
Cobalt	Greater Scaup	9	male			<0.10-0.20			
		5	female			<0.10			
Nickel	Greater Scaup	9	male			<0.10-0.43			
		5	female	0.21		<0.10-0.26			
Chromium	Greater Scaup	9	male			<1			
		5	female			<1			
Silver	Greater Scaup	9	male			<0.05			
		5	female			<0.05-0.20			

Table 5: The Use of Wing Bones for Residue Analysis (continued).

Chemical	Species	N		ppm, dry weight			% Samples with 20 ppm lead (dry weight)	Location (Date)	Reference
				Mean	Median	Range			
Lead	Green-winged Teal	347		9.1				Texas (1981-83)	Hall and Fisher, 1985
	Shoveler	55		9.7					
	Gadwall	63		9.7					
	Lesser Scaup	49		7.5					
	Pintail	18		21.6					
	Mottled Duck	21		57.1					
Arsenic	Green-winged Teal	347		14.6					
	Shoveler	55		11.8					
	Gadwall	63		5.9					
	Lesser Scaup	49		11.4					
	Pintail	18		12.2					
	Mottled Duck	21		10.3					
Lead	Brown Pelican	10		7.44 ± 2.52*				Gulf of California (1980)	Ohlendorf *et al.*, 1985
Cadmium	Brown Pelican	1		0.20					* Mean ± SD
Chromium	Brown Pelican	10		1.26 ± 0.269					
Zinc	Brown Pelican	10		108.1 ± 13.0					
Lead	Turkey Vulture	1	breeding/ male	3.5				California (1981)	Wiemeyer *et al.*, 1986
		5	breeding/ female	12.0		4.3-23			
		5	non-breeding male	9.0		4.6-15			
		5	non-breeding female	11.0		1.8-43			
	Common Raven	6	breeding/ female	2.5		0.59-9.1			

Table 5: The Use of Wing Bones for Residue Analysis (continued).

Chemical	Species	N		ppm, dry weight			% Samples with 20 ppm lead (dry weight)	Location (Date)	Reference
				Mean	Median	Range			
Lead	Herring Gull	4*	adult/-	19.5		2.95-36.8	50	Great Lakes (1983)	Struger *et al*., 1987
		4*	immature/-	2.48		0.216-4.70	0		
Cadmium	Herring Gull	4*	adult/-	0.010		0.007-0.013			* Composite samples from 4 sites
		4*	immature/-	0.033		0.019-0.070			
Mercury	Herring Gull	4*	adult/-	0.141		0.094-0.196			
		4*	immature/-	0.143		0.072-0.184			
Zinc	Herring Gull	4*	adult/-	139 ± 6.06**					** Mean ± SD
		4*	immature/-	158 ± 19.3**					

Table 6: The Use of Bones (other than wing bones) for Residue Analysis.

SPECIES		TYPE OF BONE	RESIDUES	REFERENCE
Common Tern	*Sterna hirundo*	femur, tibiotarsus, fibula	Ag, Cd, Co, Cr, Cu, Hg, Pb, Zn	Connors *et al*., 1975.
Cattle Egret	*Bubulcus ibis*	"not indicated"	Pb, Cd, Mn	Hulse *et al*., 1980.
Laughing Gull	*Larus atricilla*			
Pigeon	*Columba livia*	tibiotarsus	Pb, Cd	Hutton and Goodman, 1980.
Mourning Dove	*Zenaida macroura*	femur	Pb	Kendall and Scanlon, 1979; 1982b.
Ringed Turtle Dove	*Streptopelia risoria*	femur	Pb	Kendall and Scanlon, 1981.
Rock Dove	*Columba livia*	femur	Pb	Kendall and Scanlon, 1982a.
Pigeon	*Columba livia*	femur	Pb	Ohi *et al*., 1974.
Laughing Gull	*Larus atricilla*	"not indicated"	Pb	Reid and Hacker, 1982.
Laughing Dove	*Streptopelia senegalensis*	femur, scapular, pelvis, ulna, radius, humerus	Pb	Siegfried *et al*., 1972.
Mute Swan	*Cygnus olor*	femur	Pb	Simpson *et* al., 1979.
Kestrel	*Falco sparverius*	tibia	Pb	Stendell, 1980.

Table 6: The Use of Bones (other than wing bones) for Residue Analysis (cont'd).

SPECIES		TYPE OF BONE	RESIDUES	REFERENCE
Red-billed Gull	*Larus novaehollandiae scopulinus*	tibia or skeleton	F	Stewart *et al*., 1974.
White-faced Heron	*Ardea novaehollandiae*			
Mallard	*Anas platyrhynchos*			
Black-backed Gull	*Larus dominicanus*			
Harrier Hawk	*Circus approximans*			
Pied Oystercatcher	*Haematopus ostralegus finschi*			
Hedge Sparrow	*Prunella modularis*			
Starling	*Sturnus vulgaris*			
Pukeko	*Porphyrio melatonus*			
Black-backed Gull	*Larus dominicanus*	tibia or skeleton	F, Pb	Turner *et al*., 1978.
Red-billed Gull	*Larus novaehollandiae scopulinus*			
South Island Pied Oystercatcher	*Haematopus ostralegus finschi*			
Pied Stilt	*Himantopus Himantopus leucocephalus*			
Pukeko	*Porphyrio porphyrio melanotus*			
White-fronted Goose	*Anser albinfrons*	skeleton	Sr^{90}	Van den Hoek and Eygenraam, 1965.

Table 6: The Use of Bones (other than wing bones) for Residue Analysis (cont'd).

SPECIES		TYPE OF BONE	RESIDUES	REFERENCE
Mallard	*Anas platyrhynchos*	femur	V	White and Dieter, 1978.
Greater Scaup	*Aythya marila*	sternum, skull, wing bones, backbone, upper leg bones (femur, tibiotarsus, fibula), lower leg bones (tarsometatarsus, metatarsus, phalanges)	Fe,Zn,Mn, Cu,Pb,Cd, Co,Ni,Cr, Ag	Szefer and Falandysz, 1986.
Brown Pelican	*Pelecanus occidentalis*	ribs, humerus	Pb,Cd, Cr,Zn	Ohlendorf *et al*., 1985.
Swan	*Olor columbianus*	"not indicated"	Pb	Benson *et al*., 1976.
Ring-necked Duck	*Aythya collaris*	"not indicated"	Pb	Mautino and Bell, 1986.
Eastern Great White Egret	*Egretta alba modesta*	sternum, humerus, cervical vertebrae, femur, tibia	Ca,Fe,Mn, Zn,Cu,Pb, Ni,Cd,Hg	Honda *et al*., 1985.
Black-eared Kite	*Milvus migrans lineatus*	sternum, humerus, cervical vertebra femur, tibia	Hg	Honda *et al*., 1986b.
Louisiana Heron	*Hydranassa tricolor*	"not indicated"	Pb,Cd	Cheney *et al*., 1981.
Cattle Egret	*Bubulcus ibis*			
Great Tit	*Parus major*	femur	Pb,Cd,Cu, Zn,Fe	Sawicka-Kapusta *et al*., 1986.
Coal Tit	*Parus ater*			
Crested Tit	*Parus cristatus*			

Table 7: Lead Levels (ppm, Wet Weight) in Mallards Fed a Single Lead Shot That Died or Were Sacrificed (from Longcore *et al.*, 1974b).

DAYS TILL DEATH		KIDNEY	LIVER	BREAST MUSCLE	PANCREAS	BRAIN	TIBIA
4	Died	94 - 128	32 - 61	0.7 - 0.9	208 - 228	2.1 - 2.6	100 - 109
4	Sacrificed	107 - 181	52 - 55	1.2 - 1.7	129 - 224	3.5 - 4.7	82 - 93
8	Died	206 - 299	58 - 63	0.9 - 1.1	72 - 185	4.7	94 - 167
8	Sacrificed	59 - 142	50 - 51	1.1	91 - 212	3.2 - 4.1	111 - 121
10	Died	80 - 131	54	0.6 - 1.1	119 - 697	4.5 - 6.0	102 - 191
10	Sacrificed	78 - 79	37 - 65	0.9 - 1.6	131 - 227	2.8 - 3.0	125 - 137
14	Died	69 - 109	43 - 46	0.7 - 0.9	77 - 302	3.1 - 5.7	111 - 150
14	Sacrificed	77 - 142	39 - 46	1.1 - 2.3	79 - 522	3.5 - 3.7	142 - 155
20	Died	98	37 - 65	1.5 - 2.5	212 - 1551	7.5 - 10.6	145 - 158
20	Sacrificed	89 - 243	36 - 52	1.5 - 1.8	162 - 284	6.5 - 7.2	130 - 212
Mean	Died	175.7	57.4	1.4	389.9	4.6	136.7
	Sacrificed	104.3	44.1	1.4	212.9	3.9	126.7

Table 8: Summary of the Two Nationwide Surveys of Lead in Wing Bones of Waterfowl.

DATE	SPECIES	LOCATION	AGE	SEX	N	RESIDUE	MAJOR FINDINGS	REFERENCE
1972-1973	Mallard Black Duck Mottled Duck Pintail Redhead Canvasback Lesser Scaup	Nationwide (U.S.)	Adult and immature	Not separated	4,190 wings (up to 75 wing bones per sample for immature ducks and up to 25 wing bones per sample for adult ducks)	Total inorganic lead	- Lead in wing bones ranged from trace levels (<0.5) to 361 ppm. - Mottled Duck wing bones had the highest residue levels. - Lesser Scaup wing bones had the lowest residue levels. - Wing bones of adult ducks had higher lead concentrations than wing bones from immatures. - Wing bone lead levels were highest in adult and juvenile Mallard Ducks from the Atlantic Flyway followed by Mississippi, Pacific and Central Flyways.	Stendell *et al.*, 1979
1979-1980 1980-1981	Mallard Pintail Wigeon Gadwall Teal Shoveler Pochard Tufted Duck Goldeneye Mute Swan Berwick's Swan Whooper Swan	Nationwide (Britain)	Adult and immature	Not separated	1,841	Total inorganic lead	- Lead in wing bones ranged from trace levels (<0.5) to 472.9 ppm. - Mallard wing bones had the highest mean lead residues and also the greatest proportion over 20 ppm of lead. - It was not possible to identify the source of lead. - The main value of data from wing bone residues is for species and geographical comparisons.	Mudge, 1981

Table 9: The Use of Feather Mineral Patterns for Ascertaining the Population Origin of Birds.

Species	Feather Type (Part)	Chemical Elements (Method of Analysis)	Major Findings	References
Snow Goose (*Anser caerulescens*)	Primary wing feathers (vane portions; but excluded the basal quarter of the vane)	Na, K, Ca, P, Fe, Zn, Mg, Mn, Cu, Si, Al, B (Flame emission spectroscopy)	-Higher Na, K, Ca and Mg values values were found in feathers of Cape Churchill geese compared to Southampton Island geese. -Higher values for P, Mn, Si, Al and B were found in feathers of Southampton Island geese. -Mineral values were similar for feathers of adult and immature geese.	Hanson and Jones, 1968
Ring-necked Pheasant (*Phasianus colchicus*)	Primary wing feathers (whole)	Na, K, Ca, Mg (Flame photometry and atomic absorption analysis)	-The differences in concentrations of elements in feathers did not reflect the concentrations of elements in the soil or in plant foods from the area when the birds were collected.	Jones *et al*., 1968
Canada Goose (*Branta canadensis*)	Tail feathers or rectrices (not indicated)	Na, Ca, Al, Mn, Cl (Neutron activation analysis)	-Canada Geese from Oregon were distiguishable from those collected in Colorado and Wisconsin by the levels of Mn in tail feathers.	Devine and Peterle, 1968

Table 9: The Use of Feather Mineral Patterns for Ascertaining the Population Origin of Birds (continued).

Species	Feather Type (Part)	Chemical Elements (Method of Analysis)	Major Findings	References
White-fronted Goose (Anser albifrons) Mallard (Anas platyrhynchos) Black Duck (Anas rubripes) Lesser Scaup (Aythya affinis)	Tail feathers of geese (not indicated) Primary, secondary and tertiary feathers of ducks (not indicated)	Ag, Al, As, C, Ca, Cu, Fe, K, Li, Mg, Mn, N, Na, P, Pb, Si, Zn (Atomic absorption-Flame emission spectrometry)	- Preliminary data of elemental levels in various feathers were presented.	Kelsall, 1970a
Mallard (Anas platyrhynchos)	Flight feathers (vanes only or whole feathers)	Ca, Cu, Mn, Zn (Atomic absorption-Flame emission spectrometry)	-Vanes were more highly mineralized than shafts for all four elements. -Less variability was reported in results for whole feather analysis than vane only analysis.	Kelsall, 1970b
Mallard (Anas platyrhynchos) Black Duck (Anas rubripes) Lesser Scaup (Aythya affinis)	Primary feathers (whole)	Ca, Cu, Fe, Mg, Mn, P, K, Si, Na, S, Zn (Atomic absorption-Flame emission spectrometry)	-Large variations in chemical composition of feathers from the same group exists. -Significant differences were detected for the feather chemistry among the three duck species. -Sex differences in feather chemistry were found in lesser scaup -Zn, Fe, Ca, K, P and Cu were discriminating elements for separating the birds by species and sex.	Kelsall and Calaprice, 1972

Table 9: The Use of Feather Mineral Patterns for Ascertaining the Population Origin of Birds (continued).

Species	Feather Type (Part)	Chemical Elements (Method of Analysis)	Major Findings	References
Ross' Goose (*Anser rossii*)	Primary feathers (vane portions)	Cu (Flame emission spectroscopy)	-Feathers of adult female geese contained higher Cu levels than feathers of adult male geese.	Hanson and Jones, 1974
Snow Goose (*Anser caerulescens*)	Primary feathers (whole)	Na, Ca, K, Cu, Fe, Mg, Mn, Zn, Si. (Atomic absorption and flame emission spectrometer)	-No chemical differences were found between feathers of the left and right wings of geese, except for Ca levels. -Age differences were found for the levels of Na, Ca, Cu, Fe, Mg, Mn, Zn and Si which were attributed to different feeding habits between adult and young of the year geese as well as different chemical requirements for growth. -Sex differences were found for the levels of K, Na, Cu, Fe, Mg and Si which were attributed to different food habits, and physiological and metabolic processes associated with sex. -Large chemical variability exists between individual primary feathers with primaries 4 and 5 being most highly mineralized.	Kelsall *et al*., 1975a

Table 9: The Use of Feather Mineral Patterns for Ascertaining the Population Origin of Birds (continued).

Species	Feather Type (Part)	Chemical Elements (Method of Analysis)	Major Findings	References
Mallard (*Anas platyrhynchos*) Black Duck (*Anas rubripes*) Lesser Scaup (*Aythya affinis*)	Primary feathers (whole)	Na, Mg, Si, K, Ca, Mn, Fe, Cu, Zn (Flame emission spectroscopy and atomic absorption spectroscopy)	-Species, sex and year-class differences in chemical content of feathers were evident with year-class differences being the most discriminating in the classification of unknowns.	Kelsall *et al*., 1975b
Snow Goose (*Anser caerulescens*)	Fourth primary feathers (vane or shaft portions)	Na, Mg, Al, Si, S, Cl, K, Ca, Mn, Fe, Cr, Zn (Electron beam analysis)	-Vane portions (N=2) were more highly mineralized and contained a wider variety of elements than the shaft. -A feather of a La Pérouse Bay colony goose could be distinguished from a goose from the Anderson River colony.	Kelsall *et al*., 1975c
Snow Goose (*Anser caerulescens*)	Primary feathers (whole and partly-grown feathers)	Ca, K, Na, Cu, Fe, Mn, Mg, Si, Zn (Flame emission and atomic absorption spectrometer)	-Whole feathers contain more Si, Ca, Fe, Mg and Mn, and less Na and K, than partly-grown feathers. -Significant differences in all minerals were found between primary nos. 1 and 10 with the first several primaries being more highly mineralized than the others. -Zn concentrations showed sex differences. -Si and Fe levels differed be- left and right wings.	Kelsall and Pannekoek, 1976

Table 9: The Use of Feather Mineral Patterns for Ascertaining the Population Origin of Birds (continued).

Species	Feather Type (Part)	Chemical Elements (Method of Analysis)	Major Findings	References
Snow Goose (*Anser caerulescens*) Ross' Goose (*Anser rossii*)	Primary feathers (mostly vane portions, some shafts)	Ca, Mg, Na, K, P, Fe, Zn, Mn, Cu, B, Si, Al	-A compilation of quantitative data on twelve minerals in feathers of over 3000 wild geese from colonies in areas of Hudson Bay, James Bay and the Arctic. -A thorough review and discussion of the biogeochemistry of feather minerals is presented.	Hanson and Jones, 1976
Snow Goose (*Anser caerulescens*)	Fifth primary feathers (whole)	Ba, Ca, I, Cl, Cu, Br, K (X-ray spectrometry)	-The analysis of chemical elements in feathers allowed for the discrimination of 89-92% of three known and 72-79% of three unknown geographically distinct goose populations.	Kelsall and Burton, 1977
Snow Goose (*Anser caerulescens*)	Fifth primary feathers (whole)	S, Cl, K, Ca, Ti, Ba, I, V, Mn, Fe, Co, Cu, Zn, Pb, Br (X-ray spectrometry)	-A sample size of 40 was adequate for discriminating three goose populations and overrode the chemical differences attributed to sex, age and changes within the feather year.	Kelsall and Burton, 1979
Whooping Crane (*Grus americana*)	Primary and secondary feathers (vane and shaft)	Ag, Al, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Si, Sr, Ti, V, Zn (Plasma optical emmision spectroscopy)	-Primary feathers contained more Ag, K, Mn, Sr and Zn, and less Al, Cd, Fe and Ti, than secondary feathers. -Vanes contained higher levels of all elements except Na than the shafts.	Carlisle, 1979 (unpublished data)

Table 9: The Use of Feather Mineral Patterns for Ascertaining the Population Origin of Birds (continued).

Species	Feather Type (Part)	Chemical Elements (Method of Analysis)	Major Findings	References
Peregrine Falcon (*Falco peregrinus*)	Fifth secondary feathers (distal 1 cm tip)	I, Mn, Mg, Cu, V, Cl, Al, Na, Se, Hg, Br, Sc, Zn, Co (Neutron activation analysis)	-The levels of elements in feathers were capable of discriminating the geographical origins of falcons from Alaska and Greenland. -Mercury, aluminum and vanadium provided the best discriminating variables.	Parrish *et al*., 1983
Canada Goose (*Branta canadensis*)	Primary feathers (whole feather minus the shaft portion below the vane)	Na, K, Ca, Mg, Al, B, Cu, Fe, Mn, P, Si, Zn (Emission spectrometer with argon plasma source)	-Mineral profiles of feathers were significantly affected by washing techniques, sample preparation procedures, external contamination and the feather position number.	Edwards and Smith, 1984

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds.

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Pheasant (*Phasianus colchicus*) Partridge (*Perdix perdix*) Willow Grouse (*Lagopus lagopus*) Corn Bunting (*Emberiza calandra*) Peregrine (*Falco peregrinus*) Eagle-owl (*Bubo bubo*) White-tailed Eagle (*Haliaetus albicilla*) Long-eared Owl (*Asio otus*) Tawny Owl (*Strix aluco*) Buzzard (*Buteo buteo*)	Primary wing feathers and tail feathers (whole, vane, shaft)	Hg (neutron activation)	-Feathers of Swedish avifauna sampled from 1829 to 1965 were analyzed for mercury. -Mean mercury levels were low in feathers of Pheasants (100 ng/g), Partridges (280 ng/g), Peregrine Falcons (2500 ng/g), Eagle-owls (2500 ng/g) and White-tailed Eagles (6600 ng/g) collected between 1830 and 1940. -There were marked increases in mean mercury levels in feathers of Pheasants (180 to 5700 ng/g), Partridges (1050 to 6000 ng/g), Peregrine Falcons (6200 to 56,000 ng/g), Eagle-owls (12,800 to 41,000 ng/g) and White-tailed Eagles (3700 to 64,000 ng/g) collected from 1940 to 1965. -Feathers of Willow Grouse collected in areas remote from agricultural districts did not show any increase in mercury levels (220 ng/g) between 1847 and 1950.	Berg *et al*., 1966.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Hen Harrier (*Circus cyaneus*)			-Variations in mercury levels among species were attributed to differences in food habits. -The 10 to 20 times increase in feather mercury after 1940 was attributed to the use of mercurial seed dressings.	Berg *et al*., 1966. (continued)
Ring-necked Pheasant (*Phasianus colchicus*)	Unspecified feathers (not indicated)	Hg (dithizone technique)	-Elevated mercury levels in feathers (0.90 to 79.4 ng/g) were found in pheasant from areas where methyl mercury dicyandiamide was used as seed grain treatment.	Tejning, 1967b.
Great-crested Grebe (*Podiceps cristatus*) Osprey (*Pandion haliaetus*)	Primary wing feathers (not indicated)	Hg (not indicated)	-Mercury levels in feathers of these two fish-eating birds collected from 1840 to 1966 reflect the history of general mercury contamination in Swedish aquatic systems. - Mercury values of Osprey feathers grown in Sweden were higher (13,700 to 20,000 ng/g) than feathers grown in the wintering areas in Africa or the Mediterranean region (1,750 to 2,300 ng/g).	Johnels *et al*., 1968.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Goshawk (*Accipiter gentilis*)	Unspecified feathers (not indicated)	Hg (not indicated)	-Mean mercury levels in feathers of Goshawks collected from 1863 to 1946 were low (2200 ng/g) compared to feathers collected from 1947 to 1965 (29,000 ng/g).	Johnels and Westermark, 1969.
Goshawk (*Accipiter gentilis*) Buzzard (*Buteo buteo*)	Primary and secondary wing feathers (inner side of the calamus)	Hg (neutron activation)	-Mercury levels in feathers of Goshawk collected during 1966-1967 in the Netherlands ranged from 5 to 72 ng/g. -Mercury levels in feathers of Buzzards collected from 1925 to 1951 ranged from 1 to 11 ng/g, while feathers collected in 1966 ranged from 2 to 23 ng/g. -External contamination was avoided by using the inner side of the calamus.	Spronk and Hartog, 1970.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Wilson's Petrel (*Oceanites oceanicus*) Snow Petrel (*Pagodroma nivea*) Ashy Petrel (*Oceanodroma homochroa*)	Tail feathers (not indicated)	Hg (atomic absorption)	-Mean concentrations of mercury in tail feathers were lower in Wilson's and Snow Petrels from Antarctica (1.77 to 2.44 ppm, wet weight) than Ashy Petrels from California (4.86 ppm).	Anderlini *et al*., 1972.
Ring-necked Pheasants (*Phasianus colchicus*)	Back feathers (not indicated)	Hg (neutron activation)	-Mercury concentrations were reported in feathers (0.008 to 12.40 ppm, dry weight) and breast muscle (0.008 to 7.6 ppm) of pheasants collected in Idaho. -Feather-muscle associations showed that 91% of feather samples had detectable mercury levels if the corresponding muscle had mercury present. -Levels of mercury in feathers showed greater variation at low levels than the corresponding muscle samples.	Huckabee *et al*., 1972.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
White-tailed Eagle (*Haliaetus albicilla*)	Unspecified feathers (not indicated)	Hg (neutron activation)	-Mercury levels in feathers of White-tailed Eagles from the Archipelago of Stockholm were high (25 to 51 ppm) compared to those from the northern part of Sweden (0.91 to 1.2 ppm).	Jensen *et al*., 1972.
Guillemot (*Uria aalge*)	Secondary wing feathers (not indicated)	Hg (neutron activation)	-Mean mercury content in secondary feathers of Guillemots from the Baltic collected during 1906 to 1925 were lower (2.7 ppm) than those collected in 1969 (5.4 ppm).	
Pintail (*Anas acuta*)	Primary wing feather No. 1 (whole)	Hg (atomic absorption)	-The first innermost primary was selected for analysis because it was the best preserved in wings of ducks submitted by hunters. -Primaries of adults and of immatures contained higher mean mercury levels (1.29 and 1.40 ppm, respectively) than breast muscles (0.11 and 0.07 ppm, respectively). -A correlation was found between mercury residues in primaries and breast muscle of adult Pintails (r=0.6436), but not in immature Pintails.	Vermeer and Armstrong, 1972b.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Great Blue Heron (Ardea herodias) Black-crowned Night Heron (Nycticorax nycticorax) American Egret (Casmerodius albus)	Primary wing feathers (not indicated)	Hg (atomic absorption)	-Mean mercury concentrations were highest in feathers (3.15 to 11.53 ppm) compared with other tissues examined (brain, breast muscle, liver). -Differences in mercury levels according to tissues, species, age and location were evident.	Hoffman and Curnow, 1973.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Bobwhite Quail (Colinus virginianus)	Primary wing feathers (distal end)	Hg (not indicated)	-Mercury residues in Bobwhite Quail feathers averaged 3.04 ppm ranging from 1.70 to 5.37 ppm. -Average mercury levels in feathers were 11 to 39 times greater than those in breast muscle. -No geographical difference in feather mercury was detected in three sampling sites in Tennessee. -No significant differences were found in mercury levels between 1969 and 1970 samples. -Newly-grown primaries of juvenile quail obtained in January contained a mean mercury level of 0.75 ppm while old feathers collected in November prior to molt contained a mean mercury level of 3.04 ppm.	Whitehead, 1973.
Pigeon (Columba livia)	Tail feathers (not indicated)	Hg (Atomic absorption)	-Total mercury residues in feathers, brain, skin, scales, liver, breast, bones, blood, heart, claws, oil glands and feces of Pigeons from Mississippi were analyzed.	Knight and Harvey, 1974.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Marsh Harrier (Circus aeruginosus) Buzzard (Buteo buteo) Long-eared Owl (Asio otus) Tawny Owl (Strix aluco) Hooded Crow (Corvus cornix) Hen Harrier (Circus cyaneus) Yellowhammer (Emberiza citrinella) Starling (Sturnus vulgaris) Barn Owl (Tyto alba) Goshawk (Accipiter gentilis)	Unspecified feathers (Proximal part of the shaft)	Hg (neutron activation)	-The analysis of mercury in feathers of terrestrial birds from Sweden collected from 1966 to 1969 showed levels (2.0 ng/g) similar to feather samples collected prior to 1940. -The decrease in mercury concentrations in feathers from 1940-1966 to 1966-1969 was reported to reflect the ban on alkyl mercury use as a seed dressing agent in agriculture in 1966.	Westermark et al., 1975.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
House Sparrow (Passer domesticus) Starling (Sturnus vulgaris) Grackle (Quiscalus quiscala) Robin (Turdus migratorius)	Unspecified (not indicated)	Pb (atomic absorption)	-Average lead concentrations were higher in feathers (and other tissues) of birds from an urban area (79.7 to 225.1 ppm, dry weight) than feathers of birds from rural areas (6.4 to 36 ppm).	Getz et al., 1977.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Black Duck (*Anas rubripes*) Mallard (*Anas platyrhynchos*)	Primary wing feather Nos. 1 to 10 (whole)	Cu, Ni, Zn (X-ray fluorescence spectrometry)	-Mean zinc levels in feathers of five duck populations were similar (119 to 124 ppm) suggesting metabolic control of this metal in these birds. -Mean copper levels were highest in feathers of ducks collected near a smelter (16 ppm) and decreased as the distance of the collection site to the smelter increased. -High mean nickel levels (5.3 ppm) were found in duck feathers collected near the smelter and low mean levels were found at other collection sites (0.2 to 1.6 ppm). -The lack of any observed trends in copper and nickel levels in feathers with respect to species sex, age and choice of wing analyzed may be a result of external absorption and binding of these metal ions by physico-chemical processes.	Ranta *et al*., 1978.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
American Coot (*Fulica americana*) Horned Grebe (*Podiceps auritus*) Lesser Scaup (*Aythya affinis*) Bufflehead (*Bucephala albeola*) Ruddy Duck (*Oxyura jamaicensis*)	Primary wing feathers (not indicated)	Hg (atomic absorption)	-Levels of mercury in feathers of coot (0.44 ppm, wet weight) were compared with feathers of Horned Grebe (6.84 ppm), Bufflehead (1.75 ppm), Lesser Scaup (1.55 ppm) and Ruddy Duck (0.80 ppm) which relates to the amount of animal matter in the diet of each species. -Mercury residues in feather samples of coot were not affected by the month of collection or the location of collection within the reservoir.	Clay *et al.*, 1979.
Great Blue Heron (*Ardea herodias*) Black-crowned Night Heron (*Nycticorax nycticorax*) Great Egret (*Casmerodius albus*)	Primary wing feathers (not indicated)	Hg (atomic absorption)	-Mercury concentrations in feathers of Great Blue Herons (3.99 to 7.26 ppm, wet weight), Black-crowned Night Herons (5.30 to 9.00 ppm), and Great Egrets (5.84 to 6.57 ppm) from the southwestern Lake Erie area were analyzed and correlated to feeding habits.	Hoffman and Curnow, 1979.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Great Skua (Catharacta skua)	Primary wing feathers (not indicated)	Hg (atomic absorption)	-Mercury levels in feathers of skuas from the North Atlantic ranged from 1.8 to 15.1 ppm, dry weight. -Mercury levels in feathers appeared to correlate with levels in the livers.	Furness and Hutton, 1979.
Puffin (Fratercula arctica) Fulmar (Fulmaris glacialis) Manx Shearwater (Puffinus puffinus)	Primary wing feathers (not indicated)	Hg, Cd, Zn (atomic absorption)	-Mean levels of zinc in feathers of Puffin (108 ppm, dry weight), Manx Shearwater (86.8 ppm), and Fulmar (97.3 ppm) were analyzed. -Cadmium was detectable in only a few feather samples. -The mean level of mercury in feathers of the Puffin was high (7.94 ppm, dry weight) compared with feathers of the Fulmar (3.34 ppm) and Manx Shearwater (1.15 ppm).	Osborn et al., 1979.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
European Starling (*Sturnus vulgaris*) Great Tit (*Parus major*) House Sparrow (*Passer domesticus*) Chaffinch (*Fringilla coelebs*)	Entire plumage (not indicated)	Cd, Pb, Zn (atomic absorption)	-Concentration of heavy metals in birds from the zincmill surroundings was higher than in birds from the surroundings of a steelworks and from a control forest. -In areas with considerable emission of cadmium and lead, these elements are stored mainly in feathers. -Correlation coefficients of cadmium and lead levels in feathers and carcass are too low, and so analysis of feathers only cannot be used as an objective indicator of concentrations of these metals in birds.	Dmowski and Karolewski, 1979.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Turkey (*Meleagris gallopava*)	Primary wing feather No. 10 (not indicated)	Cd, Ni, Pb, Zn (atomic absorption)	-Mean levels of lead (20.6 to 33.12 ug/g, dry weight), cadmium (0.18 to 0.03 ng/g), nickel (0.81 to 3.95 ug/g) and zinc (89.03 to 95.9 ug/g) in feathers of Wild Turkey from two regions of Virginia were determined. -Zinc and cadmium levels were higher in feathers of adults compared with juveniles. -Lead and nickel concentrations did not vary by age, sex, or collection site.	Scanlon *et al*., 1979a.
Woodcock (*Philohela minor*)	Primary wing feather Nos. 1 to 10 (not indicated)	Pb (atomic absorption)	-Lead residues in feathers of Woodcocks from 32 states ranged from 4.51 to 29.79 ppm, dry weight. -Lead levels differed significantly among some states but did vary by sex or age of the birds.	Scanlon *et al*., 1979b.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Mallard (*Anas platyrhynchos*) Shoveler (*Anas clypeata*) Gadwall (*Anas strepera*) American Wigeon (*Anas americana*) Green-winged Teal (*Anas crecca*) Blue-winged Teal (*Anas discors*) Canvasback (*Aythya valisineria*) Lesser Scaup (*Aythya affinis*) Ring-necked Duck (*Aythya collaris*) Ruddy Duck (*Oxyura jamaicensis*) Hooded Merganser (*Lophodytes cucullatus*)	Primary wing feather Nos. 6 to 10 (whole)	Hg (atomic absorption)	-The mean mercury level in primary feathers of adult dabbling ducks (2.67 ppm, wet weight) was higher than immature dabblers (1.34 ppm) from Manitoba. -The means for adult and immature diving ducks were 1.48 ppm and 1.11 ppm, respectively. -Statistical correlations were found between feather-liver and feather-breast muscle mercury residues of adult dabbling ducks captured in the spring and immature dabbling ducks collected in the fall. - A statistical correlation was also reported for feather-liver mercury levels of immature diving ducks.	Driver and Derksen, 1980.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Sooty Shearwater (*Puffinus griseus*) Peruvian Booby (*Sula variegata*) Guanay Cormorant (*Phalacrocorax bougainvillii*) Red-legged Cormorant (*Phalacrocorax gaimardii*) Inca Tern (*Larosterna inca*)	Primary wing feather Nos. 1 to 7 and breast feathers (not indicated)	Hg (mercury vapour meter)	-Mean mercury levels in breast feathers of five seabirds from Peru ranged between 0.43 and 1.98 ppm, dry weight. -The low variance within species and similar mean mercury values indicate that geographical factors (different exposures to chemicals) and ecological factors (different trophic levels) play bigger roles than taxonomic factors (variation among species) in mercury levels in feathers of these birds. -Mercury concentrations in primary wing feather nos. 1 to 7 of two Peruvian Boobies showed a temporal trend which may be related to their molting sequence.	Gochfeld, 1980.
Osprey (*Pandion haliaetus*)	Mantle feathers (whole) Primary wing and tail feathers (middle vanes)	Hg (neutron activation)	-Mercury in feathers of nestling Ospreys from Lapland and southwest Finland contained mean levels of 3.4 and 4.5 ppm while feathers of nestlings from known mercury-polluted areas of Finland averaged 18.3 to 24.7 ppm mercury in feathers.	Hakkinen and Hasanen, 1980.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Ruffed Grouse (*Bonasa umbellus*)	Primary wing feathers (not indicated)	Ag, Cd, Cu, Ni, Pb, Zn (atomic absorption)	-Mean levels of lead (6.4 ppm, dry weight), cadmium (0.74 ppm), nickel (0.05 ppm), zinc (94 ppm), copper (4.2 ppm) and silver (0.01 ppm) in feathers of grouse were reported to be representative of background values in remote areas of Virginia.	Scanlon *et al*., 1980.
Sooty Tern (*Sterna fuscata*)	Tail feathers (not indicated)	Cd, Hg, Se (neutron activation)	-Mean levels of cadmium (4.25 ppm, wet weight), mercury (5.44 ppm) and selenium (18.67 ppm) were measured in rectrices as well as egg, brain, blood, bone, fat, kidney, liver, muscle, stomach contents and feces of terns from Florida.	Stoneburner *et al*., 1980
Eagle-owl (*Bubo bubo*)	Primary wing feathers (proximal or distal part of the shaft)	Hg (neutron activation)	-Mean mercury levels in feathers of Eagle-owls from inland populations (3200 ng/g) were significantly lower than those from coastal populations (6510 ng/g). -A significant decrease in mercury levels in feathers of inland Eagle-owls occurred from 1967 to 1972.	Broo and Odsjo, 1981.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Goshawk (*Accipiter gentilis*)	Primary and secondary wing feathers, tail feathers, back feathers, down feathers (not indicated)	Cd, Pb (not indicated)	-Variation in cadmium and lead levels was studied in feathers of an adult female Goshawk and factors of 8 and 25 were reported for variations in cadmium and lead levels between feathers, respectively. -These variations were believed to be related to the diet of the bird during the period of feather development. -Molted primary nos. 1 to 3 of adult female Goshawks were found suitable for chemical analysis.	Ellenberg and Dietrich 1981.
Crested Tern (*Sterna bergii*)	Primary wing feather No. 4 (whole)	Cd, Cu, Pb, Zn (atomic absorption)	-Feathers of birds from an industrialized area did not differ in the levels of metal contamination compared to those from a non-industrialized area.	Howarth *et al*., 1981.
Herring Gull (*Larus argentatus*) Oystercatcher (*Haematopus ostralegus*) Great Skua (*Catharacta skua*)	Primary wing feather and back feathers (not indicated)	Hg, Zn (atomic absorption)	-Interspecific differences in the levels of metals in feathers (and kidney, liver, brain, muscle, bone) were found and are believed to be related to the feeding behavior of seabirds and to the extent of contamination of their habitat.	Hutton, 1981.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Sparrowhawk (*Accipiter nisus*)	Primary and secondary wing feathers, and tail feathers (whole feather minus the quill)	Hg (atomic absorption)	-The mercury content between feathers of a single bird varied widely (2 to 20 ng/g) which seemed to reflect the molting pattern.	Buhler and Norheim, 1981.
Ringed-turtle Dove (*Streptopelia risoria*)	Primary wing feathers (not indicated)	Pb (atomic absorption)	-Primary feathers of juvenile doves of lead-treated parents contained higher lead levels (10.03 ppm, dry weight) than feathers of progeny of control parents (1.38 ppm). -This suggests a substantial transfer of lead to the young during feeding by parents.	Kendall and Scanlon, 1981.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Laysan Duck (*Anas laysanensis*)	Primary wing feathers (whole)	Al, Ba, Cd, Cr, Cu, Fe, Mg, Mn, Ni, Pb, Sr, Zn (plasma spectrometer)	-The levels of aluminum, chromium, nickel, lead, molybdenum and barium in feathers were below 1 ppb.	Stoneburner and Harrison, 1981a.
		Hg (graphite furnace)	-Only magnesium levels were above 1 ppm (19.0 ppm, dry weight) in these feathers.	
Sooty Tern (*Sterna fuscata*)	Tail feathers (not indicated)	Cd, Hg, Se (neutron activation)	-Higher levels of cadmium, mercury and selenium were found in feathers of terns from Florida compared with terns from Hawaii.	Stoneburner and Harrison, 1981b.
Crested Tern (*Sterna bergii*)	Primary wing feather No. 4 (whole)	Cd, Cu, Pb, Zn (atomic absorption)	-Higher cadmium levels were detected in feathers of terns following harbour dredging and ocean dumping operations compared with levels in feathers collected prior to these activities. -Lead, copper and zinc levels did not differ significantly between feathers collected before and after dredging and dumping operations.	Howarth *et al*., 1982.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Peregrine Falcon (*Falco peregrinus*)	Primary and secondary wing feathers and tail feathers (proximal part of the shaft or distal part of feather with some vane)	Hg (neutron activation)	-Mercury levels varied for different feathers from the same bird and different parts of the same feather. -The same feather from different birds also varied greatly.	Lindberg and Mearns, 1982.
Ruffed Grouse (*Bonasa umbellus*)	Primary wing feathers and tail feathers (whole feather minus the shaft portion below the vane)	Cu, Fe, Ni (atomic absorption)	-Copper, iron and nickel levels in newly grown feathers did not differ between birds collected from a contaminated site (smelter) and an uncontaminated site. -Pre-molt feathers from contaminated areas contained metal levels 7 to 20 times those found in newly grown feathers. -Age and sex of bird were not significant factors in feather metal levels of these birds. -Exogenous influences (physico-chemical surface absorption of metals from atmospheric input) played the major role instead of endogenous incorporation in copper, iron and nickel levels on the plumage of these grouse.	Rose and Parker, 1982.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Temminck's Cormorant (*Phalacrocorax filamentosus*)	Unspecified wing feathers and tail feathers (shaft, vane)	Cu, Fe, Hg, Mn, Zn (atomic absorption)	-All metal concentrations, except copper, were higher in the vane than in the shaft. -The metal concentrations in the various feathers display the following order: *Copper* -Breast feathers, wing feathers, tail feathers, wing coverts, back feathers. *Iron* -Breast feathers, back feathers, wing feathers, wing coverts, tail feathers. *Mercury* -Wing feathers, tail feathers, wing coverts, back feathers, breast feathers. *Manganese* -Breast feathers, back feathers, wing coverts, wing feathers, tail feathers. *Zinc* -Breast feathers, back feathers, wing coverts, wing feathers, tail feathers.	Doi and Fukuyama, 1983.
Red-throated Diver (*Gavia stellata*)	Wing coverts, breast and back feathers (whole)			
Ancient Auk (*Synthiliboramphus antiquus*)				
Red-breasted Merganser (*Mergus serrator*)				
Asiatic Common Gull (*Larus canus kamtschatschensis*)				
Bering Island Guillemot (*Uria aalge inornta*)				
Partridge Auk (*Brachyramphus marmoratus perdix*)				
Hornbilled Puffin (*Cerorhinca monocerata*)				

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Japanese Jungle Crow (*Corvus macrorhynchos japonensis*)				Doi and Fukuyama, 1983. (continued)
Japanese Brown Thrush (*Turdus chrysolaus chrysolaus*)				
Whooper Swan (*Cygnus cygnus*)				
Flamingo (*Phoenicopterus antiquorum*)				

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Common Loon (*Gavia immer*)	Back and belly feathers (unspecified part)	Hg (atomic absorption)	-In healthy adult loons, belly feathers contained higher mercury levels (10.7 ug/g, wet weight) than back feathers (3.75 ug/g). -In healthy juvenile loons, both belly (4.74 ug/g) and back (5.0 ug/g) feathers had similar levels of mercury. -In emaciated adult loons, higher mercury levels were detected in belly (14.9 ug/g) than back (13.4 ug/g) feathers. -In emaciated juvenile loons, higher levels of mercury were found in belly feathers (19.4 ug/g) than back feathers (12.9 ug/g). -Mean mercury levels in feathers were 25 to 30 times higher than levels in body fat and 12 to 13 times higher than in uropygial gland secretions.	Frank *et al*., 1983.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Peregrine Falcon (*Falco peregrinus*)	Primary and secondary flight feathers, and tail feathers (proximal portion of feather (shaft) or distal portion containing parts of the vane)	Hg (neutron activation)	-Feathers of falcons collected between 1971-1977 from northern Sweden contained higher levels of mercury (17.6 ppm, dry weight) than those from southern Sweden (7.78 ppm) which was related to the greater contamination of the aquatic prey species in their diet. -Mercury levels in feathers of falcons decreased during 1971-1977 compared with feathers collected between 1940-1966. -No significant differences in mercury levels in primary and tail feathers of male and female falcons were found. -Mercury levels in feathers of nestlings were lower than in their parents which was related to the shorter exposure period. -Sequential primary and rectrix analysis showed successive decreases in mercury levels which was explained by the excretion of mercury in the seasonal molt and a shift to less contaminated food.	Lindberg and Odsjo, 1983.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Peregrine Falcon (*Falco peregrinus*)	Primary and secondary flight feathers, and tail feathers (proximal portion of feather (shaft) or distal portion containing parts of the vane)	Hg (neutron activation)	-The mean level of mercury in feathers of adult falcons from Finland collected between 1975-1977 was 20.03 ug/g, dry weight. -Feathers of nestlings contained less mercury (6.95 ug/g) than adults (20.03 ug/g).	Lindberg *et al*., 1983.
Grey Heron (*Ardea cinerea*)	Primary wing feathers (whole)	Cd, Cu, Pb, Zn (atomic absorption)	-The small variations and symmetrical distribution patterns for feather copper and zinc levels suggest physiological regulation of these elements. -Lead and cadmium show greater variation and positively skewed distribution patterns which suggest environmental enrichment.	Rolev, 1983.
Long-tailed Duck (*Clangula hyemalis*)	Unspecified feathers (not indicated)	Cd, Co, Cu, Fe, Mn, Ni, Pb, Zn (atomic absorption)	-Metal levels were determined in liver, breast muscle, leg muscle, heart, stomach and feathers of male and female Long-tailed Ducks. -Metal levels in feathers of oiled birds were generally lower than those taken in fishing nets.	Szefer and Falandysz, 1983.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Guillemot (*Uria aalge*) Black Guillemot (*Cepphus grylle*)	Primary wing feathers Nos. 1 to 10 of left and right wings (shaft portion below the vane)	Hg (neutron activation)	-The effects of ultraviolet light, heating, freezing and weathering (rain, wind, sun) exposure on mercury levels in feathers were examined and the variation in concentrations of mercury was less than 10% compared with reference feathers.	Appelquist *et al*., 1984.
Pacific Black Duck (*Anas superciliosa*) Grey Teal (*Anas gibberifrons*)	Primary wing feathers (vane)	Hg (atomic absorption)	-Mercury levels were higher in feathers (3.01 ug/g, dry weight) of Pacific Black Ducks compared with wing muscle (0.09 ug/g, wet weight). -Mercury levels were higher in feathers (3.27 ug/g, dry weight) of Grey Teal compared with wing muscle (0.10 ug/g, wet weight).	Bacher and Norman, 1984.
Gyrfalcon (*Falco rusticolus*)	Primary and secondary wing feathers, tail feathers and wing covert (proximal part of feather of calamus)	Hg (neutron activation)	-Feathers of Gyrfalcons from northern Sweden contained lower levels of mercury (1.72 ppm, dry weight) compared with those of Peregrine Falcons (17.6 ppm) which was correlated to contamination of their respective prey species.	Lindberg, 1984.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
45 Asian bird species	Unspecified wing feathers and tail feathers (shaft, vane) Wing covert, breast and back feathers (whole)	Hg (atomic absorption)	-Mercury levels in feathers were correlated with the feeding habits of birds: fish-eating seabirds (7.1 ppm, wet unspecified), omnivorous waterfowl (5.5 ppm), predatory birds (3.6 ppm), omnivorous terrestrial birds (1.5 ppm), and herbivorous waterfowl (0.9 ppm). -Mercury levels in feathers of birds collected near a polluted area increased from 1955 to 1972 which was related to the discharge from industries. -Variation in mercury levels exists between the parts of a feather, and different feathers of the same bird.	Doi et al., 1984.
Finnish Sparrowhawk (*Accipiter nisus*)	Mantle feathers (whole)	Hg (atomic absorption)	-Elevated mercury levels were recorded in samples from the second half of the century and high values predominated in samples from the 1960s. -General level of mercury in the Sparrowhawk seemed to be higher than in many other species.	Solonen and Lodenius, 1984.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Knot (*Calidris canutus*) Bar-tailed Godwit (*Limosa lapponica*)	Primary wing feather No. 8 (vane, shaft and whole feather)	As, Hg, Se, Zn (neutron activation) Cd, Pb (atomic absorption)	-Metal concentrations in the vane and shaft of the feather and the whole feather were monitored and the effects of external contamination and leaching were investigated. -Mercury levels in the vane or shaft did not vary significantly with time after development and external contamination from exposure to seawater with suspended material did not affect the mercury concentrations. -Leaching of mercury from feathers washed in 3.5% KCl did not occur. -Contamination of feathers by metals in uropygial gland secretions may be possible. -A slight increase in arsenic levels in the vane, but not the shaft, with time after development and an increase in arsenic concentrations in vanes occurred following exposure to seawater. -No leaching of arsenic from the vane or shaft was detected.	Goede and de Bruin, 1984.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
			-Selenium levels in the vane, but not the shaft, increased with time after formation and vanes exposed to seawater had higher selenium levels than unexposed feathers.	Goede and de Bruin, 1984. (continued)
			-Selenium levels decreased in vanes washed in 3.5% KCl and contamination from uropygial gland secretions appeared possible.	
			-Zinc concentrations in the vane or shaft did not change significantly with time after development and after exposure to seawater.	
			-Zinc leached from the vane, but not the shaft, and contamination from uropygial gland secretions may be possible.	
			-Lead levels in the vanes, but not the shaft, increased with time after formation but no changes in lead concentrations in vanes or shaft occurred after exposure to seawater.	

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
			-The uropygial gland secretion contained low levels of lead. -No significant change in cadmium levels of the vane and shaft occurred with time after formation but the metal was detectable in only a few samples. -No change in cadmium concentrations were detected in the vane and shaft after exposure to seawater, but slight contamination of the vane and whole feather was demonstrated by autoradiography.	Goede and de Bruin, 1984. (continued)
Barn Swallow (*Hirundo rustica*)	Entire plumage (not indicated)	Pb (atomic absorption)	-Lead concentrations in feathers of adults from a highway colony (30-115 ppm) were about 3 times those in feathers of adults from a rural reference colony, but concentrations in nestlings from the two colonies were similar. -No significant difference in feather lead levels was found between sexes in either colony. -Feathers of adults contained 20 times (highway colony) and 10 times (reference colony) the lead in feathers of their young.	Grue *et al.*, 1984.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Common Guillemot (*Uria aalge*) Black Guillemot (*Cepphus grylle*) Brunnich's Guillemot (*Uria lomvia*)	Primary wing feather No. 5 (distal part of shaft)	Hg (neutron activation)	-Mercury levels in feathers were found to be higher in the Baltic and the Kattegat compared with the Faroe Islands and Greenland. -Mercury levels were almost constant for the last two areas, whereas a substantial increase during this century was found for the Baltic and Kattegat. -Mercury levels in Common Guillemots from the Baltic decreased after 1969. -Mercury levels were highest in Black Guillemots living close to the coast compared with the *Uria* species living offshore.	Appelquist *et al.*, 1985.
Knot (*Calidris canutus*) Bar-tailed Godwit (*Limosa lapponica*) Redshank (*Tringa totenus robusta*)	Primary wing feather No. 8 of adults and all primaries of juveniles (vane for Zn and Se, and shaft for Hg and As)	As, Hg, Se, Zn (neutron activation)	-Feather shafts of juvenile birds contained low levels of mercury (0.29 to 1.07 ppm, dry weight) which were similar to museum specimens collected between 1927 to 1969 (0.69 ppm). -Feather shafts of adult birds contained significantly higher mercury levels (1.96 to 10.26 ppm) than those of juveniles.	Goede, 1985.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
			-Higher mercury levels were found in birds from Vlieland than in birds from Schiermonnikoog. -Only one feather shaft of juvenile birds contained detectable levels of arsenic but elevated levels were found in adult feathers (0.47 to 3.17 ppm). -Low levels of selenium were found in vanes of juvenile feathers (3.43 to 3.68 ppm) but higher concentrations were reported in adult feathers collected between 1904 to 1965 (5.38 to 53.9 ppm) and between 1979 to 1982 (5.65 to 18.33 ppm). -Zinc levels in the vane of juvenile godwit and Redshank were lower than those in adults. -No yearly differences in zinc levels were found.	Goede, 1985. (continued)

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Knot (*Calidris canutus*) Redshank (*Tringa totanus robusta*) Bar-tailed Godwit (*Limosa lapponica*)	Primary wing feather No. 8 (vane and shaft for Cd and vane for Pb).	Cd, Pb (atomic absorption)	-Vanes of juvenile and adult birds rapidly accumulate lead in the wintering grounds. External contamination of feathers may be partially responsible for the increase in levels. -Cadmium was detected only in three shaft samples (n=80) and four vane samples (n=37). -Problems with the analytical methodology of metal determination in the feather were discussed.	Goede and de Voogt, 1985.
Dunlin (*Calidris alpina*)	Primary wing featner No. 8 (vane)	As (neutron activation)	-Higher arsenic levels were detected in feathers of adult birds compared with juveniles. -This was correlated to internal deposition of arsenic in feathers of adults during feather formation.	Goede and de Bruin, 1985.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Green-winged Teal (*Anas crecca*) Shoveler (*Anas clypeata*) Gadwall (*Anas strepera*) Lesser Scaup (*Aythya affinis*) Pintail (*Anas acuta*) Mottled Duck (*Anas fulvigula*)	Primary wing feathers (3 to 6 feathers, nos. unspecified)	As, Cd, Cr, Cu, Mn, Ni, Pb, Se, Sn (inductively coupled plasma emission)	-Shovelers had significantly greater arsenic concentrations in feathers of those individuals with ingested lead shot than those without lead shot. -Stage of feather molt must be taken into consideration before feathers can be used to predict lead ingestion.	Hall and Fisher, 1985.
Eastern Great White Egret (*Egretta alba modesta*)	Primary wing feathers, coverts and abdominals (primaries also divided into rachis and barbs)	Cd, Cu, Fe, Hg, Mn, Ni, Pb, Zn (atomic absorption)	-All metal concentrations were highest in the abdominal feathers and decreased in order of coverts and remiges. -In the primary feathers, most of the metal concentrations were much higher in the barbs than the rachis while the opposite was observed for copper. -Different feather structure may account for the variations of metal concentrations among the bodily positions of feathers.	Honda *et al*., 1985.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Brown Pelican (Pelecanus occidentalis)	Tertial feathers (not indicated)	Cd, Cu, Hg, Pb, Se, Zn (atomic absorption)	-Significant correlations were found for mercury levels between feathers and liver, and feathers and kidney as well as for lead levels between feathers and humeri.	Ohlendorf et al., 1985.
Ruffed Grouse (Bonasa umbellus) Spruce Grouse (Canachites canadensis) Willow Ptarmigan (Lagopus lagopus)	Tail feathers (not indicated)	Cu, Fe, Ni (atomic absorption)	-Nickel levels in feathers were consistently lowest (<1 ug/g) with copper levels (4 to 8 ug/g) averaging 6 to 8 times higher than nickel, and iron levels, though showing great intra- and inter-species variation, were much higher than levels of nickel or copper. -No significant interspecies differences were noted in nickel or copper levels, but there were differences in iron levels.	Parker, 1985.
Black-eared Kite (Milvus migrans lineatus)	Primary wing feathers, coverts, tail and abdominal feathers (primary feathers analyzed individually)	Hg (atomic absorption)	-Mercury levels were high in the feathers and low in the bone. -Accumulation of mercury in feathers depends on the tissue concentration of mercury.	Honda et al., 1986b.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Great Skua (*Catharacta skua*) Atlantic Petrel (*Pterodroma incerta*) Soft-plumaged Petrel (*Pterodroma mollis*) Kerguelen Petrel (*Pterodroma brevirostris*) Greater Shearwater (*Puffinus gravis*) Kittiwake (*Rissa tridactyla*) Fulmar (*Fulmaris glacialis*) Manx Shearwater (*Puffinus puffinus*)	Primary wing feathers (secondary, tail, head, neck, breast, belly, back, wing coverts, rump, tail coverts and scapular feathers for two species)	Hg (atomic absorption and neutron activation)	-Feathers replaced early in the molting sequence had higher levels of mercury than those molted later. -The low standard deviation of mercury levels in feathers from the back, belly, breast, rump and scapulars suggests that a pooled sample of several small body feathers would provide the best single measure of mercury level from the plumage of an individual bird. -Amount of mercury stored in body tissues is the main factor determining levels in plumage.	Furness *et al.*, 1986.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
European Starling (*Sturnus vulgaris*)	Entire plumage (not indicated)	Pb (atomic absorption)	-Average lead concentrations in feathers and other tissues of 18-day-old and adult female birds nesting within highway roadside verges increased with traffic volume. -Lead concentrations in carcasses of adult females and 18-day-old starlings were positively correlated (r=0.72 and r=0.88, respectively) with lead concentrations in their feathers. -Lead concentrations in carcasses and feathers of adult females and 18-day-old starlings were negatively correlated with ALAD activity in red blood cells and with haemoglobin concentration.	Grue *et al*., 1986.
Great Tit (*Parus major*) Coal Tit (*Parus ater*) Crested Tit (*Parus cristatus*)	Remiges and rectrices (not indicated)	Cd, Cu, Fe, Pb, Zn (atomic absorption)	-Concentrations of lead and cadmium attained higher levels in birds from polluted regions than in control birds whereas copper, zinc and iron did not differ significantly. -There was a strong correlation between lead concentrations in feathers and in the carcass without feathers (r=0.90).	Sawicka-Kapusta *et al*., 1986.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Herring Gull (*Larus argentatus*)	Primary feathers (whole)	Ag, Al, Cr, Cu, Fe, Mg, Mn, Zn (inductively coupled plasma emission)	-Concentrations of cadmium, lead and mercury were higher in adult gulls than in prefledged young.	Struger *et al*., 1987.
		Pb, Cd (graphite furnace atomic absorption)	-Lead levels in both age classes were generally higher in tissues (liver, kidney, bone, feathers) from the two upper Great Lakes' colonies (Lakes Huron and Superior) than from the lower Great Lakes' colonies (Lakes Erie and Ontario).	
		Hg (flameless atomic absorption)	-Cadmium and mercury levels did not vary greatly among colonies from the four locations.	
			-Levels found were below those associated with metal toxicosis in laboratory studies with other avian species.	

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Turkey Vulture (*Cathartes aura*) Common Raven (*Corvus corax*) California Condor (*Gymnogyps californianus*)	Secondary wing feathers (not indicated) Secondary wing feathers (not indicated) Flight feathers, coverts, body feathers (whole)	As, Cd, Cu, Hg, Ni, Pb, Se, Zn (atomic absorption)	-There was an inverse correlation in lead levels between bone (humeri) and secondary wing feathers in breeding female ravens. -Lead levels in bone of vultures and feathers of condors appeared to be elevated above normal background levels in some cases. -Copper levels in feathers of female breeding ravens and female non-breeding vultures were significantly higher than in female breeding vultures. -Mercury levels were significantly higher in feathers of female breeding vultures than in those of female breeding ravens, but mercury levels in both these species tended to be much lower than in condors. -Zinc levels tended to be higher in feathers of ravens than condors, whereas the difference between vultures and condors was less pronounced. -Lead concentrations appeared to be higher in feathers of condors than ravens or vultures.	Wiemeyer *et al*., 1986.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Bonaparte's Gull (*Larus philadelphia*) Herring Gull (*Larus argentatus*) Black-legged Kittiwake (*Rissa tridactyla*) Common Tern (*Sterna hirundo*) Arctic Tern (*Sterna paradisaea*) Black Guillemot (*Cepphus grylle*)	Primary wing feather Nos. 1 to 10 (whole)	Hg (atomic absorption)	-There was a progressive decrease in mercury concentration from the innermost to the outermost primary feather in species undergoing sequential molt, whereas no trend in mercury levels was apparent in species undergoing synchronous molt.	Braune, 1987.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Bonaparte's Gull (*Larus philadelphia*)	Primary wing feather Nos. 1 to 10 (whole, quill, rachis, vane) Secondary wing feathers, wing coverts, rectrices, dorsal, abdominal, head and down feathers (whole)	Hg (atomic absorption)	-Adult male gulls had significantly higher mercury levels than females in primary feather nos. 1 to 5. -Mercury levels decreased across the primary feather sequence in second-year and adult gulls. -After completion of molt, new feathers contained 93% of the mercury body burden in adults due to redistribution of mercury from body tissues to feathers. -Abdominal and down feathers had significantly higher mercury concentrations than dorsal, tail and wing feathers. -The vane contained slightly higher mercury levels than the feather rachis or quill.	Braune and Gaskin, 1987.
Mallard Duck (*Anas platyrhynchos*)	Unspecified feathers (not indicated)	Cu, Fe, Zn (atomic absorption)	-Feather levels of zinc were not statistically different between treatment groups (low dose - 5 zinc shot, high dose - 10 zinc shot, control - 0 zinc shot). -Ingested zinc metal shot probably presents no detectable health threat to wild birds.	French *et al*., 1987.

Table 10: The Use of Feathers for Monitoring Environmental Residues in Birds (continued).

Species	Feather Type (Part)	Residue (Analytical Method)	Major Findings	References
Greater Scaup (*Aythya marila*)	Unspecified feathers (not indicated)	Cd, Cu, Co, Fe, Mn, Ni, Pb, Zn (atomic absorption)	-Metal levels were determined in liver, kidney, lung, breast muscle, stomach, heart, brain, eyeballs, uropygial gland, tongue, skin, feathers and stomach contents of male and female scaup. -No significant sex-related variations were noted for any of the metals. -Levels of cadmium, iron and manganese in feathers of scaup were 3 to 4 times higher than reported for Long-tailed Ducks from the same area. Levels were also higher for cobalt and nickel whereas similar levels of lead, copper and zinc were found for the two species. -Metal transfer ratios (metal concentration in predator/metal concentration in prey) were generally less than 1 for cadmium, lead, nickel, manganese, cobalt and iron, and greater than 1 for copper and zinc.	Szefer and Falandysz, 1987.

8.0 APPENDIX A: GUIDELINES FOR THE SELECTION OF CHEMICAL MONITORING SPECIES

The selection of an "ideal" species for monitoring environmental contamination is not a simple matter. The purpose of some studies is to monitor the distribution and trends of chemical residues in the environment through the use of a monitoring species, or alternatively, some studies may focus on the monitoring of distribution and trends in effects of chemical residues on organisms. Historically, most studies are of the former type. The choice is, of course, dependent on the specific objectives and priorities of the program. The following criteria, however, must always be carefully considered in attempting to meet the monitoring needs.

1) Availability The selected species should have stable population densities which can withstand the effects of systematic sampling. They must be sufficiently abundant in number so as to provide statistically adequate sample sizes. On a practical basis, the collection of the specimens should be easy and inexpensive.

2) Distribution The candidate species should be widely distributed throughout the area to be surveyed. This is particularly important for the monitoring of geographical trends of environmental contamination. In some situations where the choice species is not available in a particular region, it may be possibe to use a substitute or ecological equivalent from the area. The alternate

species, however, should have a similar propensity for residue encounter and accumulation.

3) Mobility — Information on the mobility and range of the monitoring species should be available. The extent of daily and seasonal movements has to be considered. For surveying local pollution or for associating residues with a particular area (point source), a resident or sedentary species would be a good selection. To measure changes in contamination over a large area, a mobile or migratory species would be suitable. The use of migratory species requires some knowledge of their migration patterns. In addition, the extent of movements at both ends of their migration should be known. Caution should be exercised when selecting a migratory species as a chemical monitor. Adequate information on their movements and rates of residue accumulation must be acquired.

4) Diet — The food habits of the selected species should be known since one of the major routes of exposure is the diet. The food consumed by the species should be representative of the segment of the environment being studied. For example, residues in tissues of piscivorous species are likely to reflect contamination of their food items from aquatic systems. Generally, persistent compounds are

concentrated along the food chain or biomagnified. Therefore, herbivorous species will tend to have lower residue burdens than omnivores, which in turn will have lower levels than carnivores.

5) Habitat

The selected species should obviously live in the segment of the environment being monitored and the chemical residues in the specimens should reflect the contamination of the area.

6) Physiology

The selected species must be able to acquire the residues of concern and accumulate them (or their metabolic product) to greater concentrations than those in their food or surrounding environment. A species which can rapidly excrete residues or suffer deleterious effects at low levels may not be suitable for purposes of monitoring the distribution and trends of chemical residues even though such a species may be suitable for monitoring the distribution and trends in effects of chemical residues on organisms. Ideally, the selected species should maintain a physiological condition which is unchanged by age, sex and season. There is, of course, no such species. Therefore, information on these factors, which can influence the uptake, tissue distribution, metabolism and excretion of the residue in the species, should be acquired.

In practice, no single avian species can successfully fulfill all the above requirements. Often, some compromise in the selection of a species or the design of the monitoring survey are necessary. These adjustments should be carefully deliberated so that they do not provide unreliable information and affect the objectives of the monitoring program.

9.0 APPENDIX B: A SUMMARY OF THE CANADIAN MIGRATORY GAMEBIRD SPECIES COMPOSITION SURVEY

The Species Composition Survey (SCS) in Canada is an annual survey that was implemented in 1967 to provide information on the population levels and reproductive success of harvested gamebirds (Cooch *et al*., 1978). Selected hunting permit purchasers are requested to submit waterfowl parts (wings of ducks and tail fans or rectrices of geese), so the species, age and sex composition of their harvest can be calculated. Information concerning the place, time and date of kill is requested from the respondents. The band number, when it is available, is also requested. The submitted waterfowl parts with incomplete informatin on hunting location and date are excluded from the harvest estimates. The duck and goose species surveyed in the SCS are listed in Tables I and II, respectively.

According to 1986 statistics (Table III), 23,909 sets of wing envelopes (5 or 10 envelopes per hunter) were sent to permit purchasers from across Canada (Dickson and Métras, 1987). This is 6.3% of the 379,821 individuals who purchased a hunting permit in 1986. The sampling intensity for the SCS is not uniform across the country, but varies among geographical zones (Table III). The highest proportion of hunters being sampled is found in zones 1 and 2 of Nova Scotia. The lowest proportion of sampled hunters is found in zones 1 and 3 of Saskatchewan. The overall percentage of responses across Canada in 1986 was 16% (Dickson and Métras, 1987). The rate of response also varied according to geographical zones (Table III). The number of returns for which band numbers are included is low. According to 1987 statistics, less than 1% of the responses in the SCS provided a band number (Dickson, pers. comm., 1988).

Some of the difficulties and bias (sampling and response) of the SCS have previously been documented (Cooch _et al_., 1978). Problems concerning the transmission of body parts through the postal system still exist. The wings are often received from hunters with unwanted parts such as fragments of skin, muscle, bones and blood. As well, some birds are kept unfrozen prior to submission. At times, some wings are not identifiable because of their advanced state of decomposition. These parts are discarded and are not included in the kill estimates. At present, wing envelopes contain a plastic liner to avoid problems with odor, blood stains and maggots which existed earlier with paper packaging.

The SCS is designed to maximize the return of waterfowl parts from hunters, therefore, sampling bias can be a factor (Cooch _et al_., 1978). Two sources of sampling bias include: (1) the deliberate sampling of respondents from the previous year which would involve a greater sample of active and successful hunters and (2) the dealing out of wing envelopes from sampled hunters to other individuals whose experience and success are unknown.

Response bias is also a matter of concern to the SCS (Cooch _et al_., 1978). Some hunters may submit a non-representative selection of their harvest. This may occur when hunters purposely send a particular wing because of the prestige of harvesting such a species or because they cannot identify it. These biases are continually compensated for and adjusted. The results of the SCS are computed with the National Harvest Survey data to yield harvest estimates by species.

Table I: A List of Duck Species for Which Wings are Collected in the SCS.

Common Name	Scientific Name
Common Merganser	*Mergus merganser*
Red-breasted Merganser	*Mergus serrator*
Hooded Merganser	*Lophodytes cucullatus*
Mallard	*Anas platyrhynchos*
Black Duck	*Anas rubripes*
Gadwall	*Anas strepera*
European Wigeon	*Anas penelope*
American Wigeon	*Anas americana*
Green-winged Teal	*Anas crecca*
Blue-winged Teal	*Anas discors*
Shoveler	*Anas clypeata*
Pintail	*Anas acuta*
Wood Duck	*Aix sponsa*
Redhead	*Aythya americana*
Canvasback	*Aythya valisineria*
Greater Scaup	*Aythya marila*
Lesser Scaup	*Aythya affinis*
Ring-necked Duck	*Aythya collaris*
Common Goldeneye	*Bucephala clangula*
Barrow's Goldeneye	*Bucephala islandica*
Bufflehead	*Bucephala albeola*
Oldsquaw	*Clangula hyemalis*
Harlequin Duck	*Histrionicus histrionicus*
Common Eider	*Somateria mollissima*
King Eider	*Somateria spectabilis*
Black Scoter	*Melanitta nigra*
White-winged Scoter	*Melanitta fusca*
Surf Scoter	*Melanitta perspicillata*
Ruddy Duck	*Oxyura jamaicensis*

Table II: A List of Goose Species for Which Tail Fans are Collected in the SCS.

Common Name	Scientific Name
Snow Goose	*Chen caerulescens*
Ross' Goose	*Chen rossii*
White-fronted Goose	*Anser albifrons*
Canada Goose	*Branta canadensis*
Brant	*Branta bernicla*

Table III: Sampling Intensity and Response in the SCS, 1986 (adapted from Dickson and Métras, 1987).

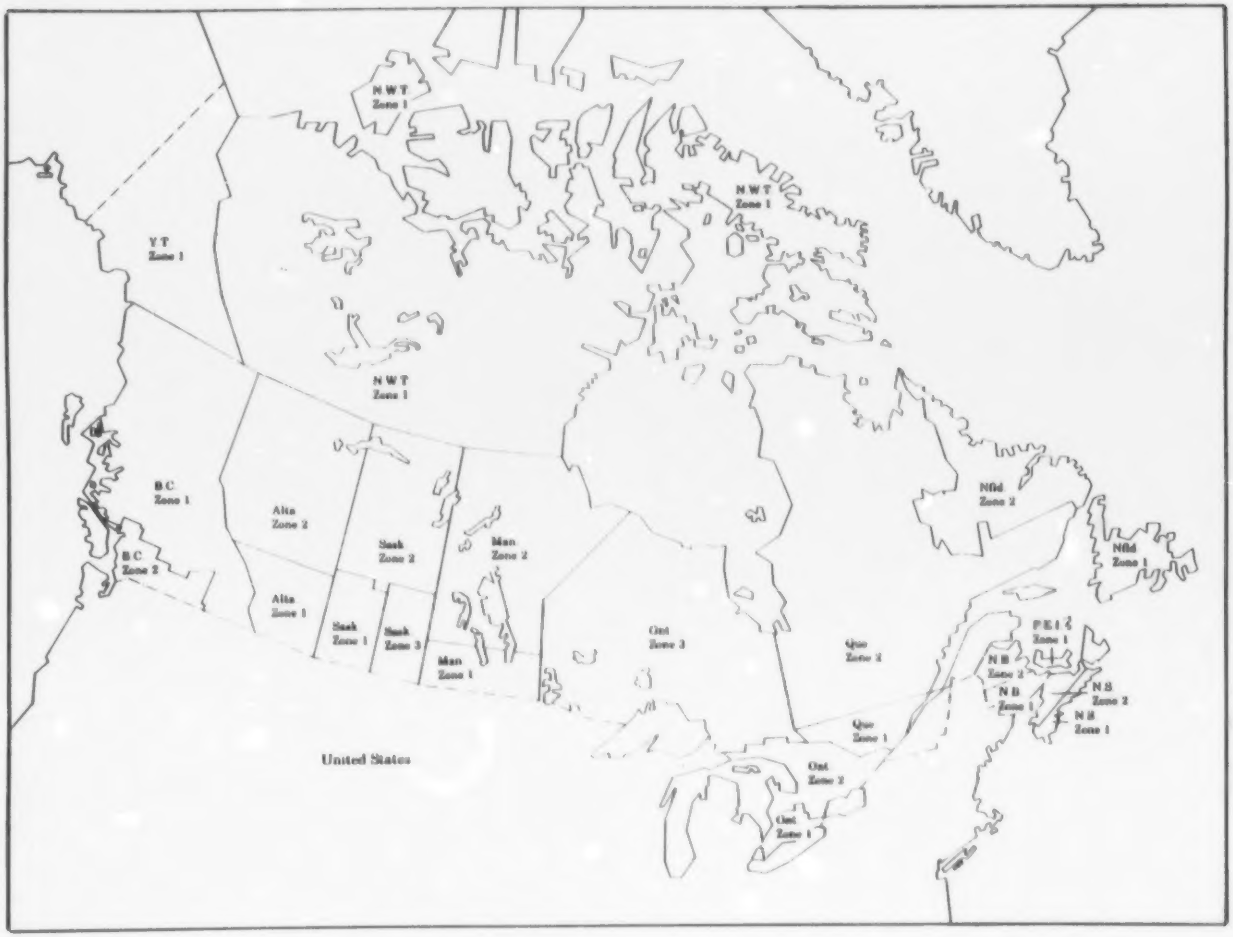
	Zone*	Sampling Intensity**(%)	Response Rate ***(%)	Parts Received
Nfld	1	4.1	13.0	445
	2	18.3	7.6	147
PEI	1	19.3	8.8	366
NS	1	25.5	10.4	1167
	2	27.5	12.1	710
NB	1	9.9	17.0	856
	2	24.1	8.7	319
Que	1	4.3	24.0	2809
	2	9.5	18.5	1427
Ont	1	4.9	18.5	2065
	2	3.5	22.9	3114
	3	9.8	13.1	1399
Man	1	3.3	26.1	1358
	2	4.9	13.9	228
Sask	1	2.9	24.3	539
	2	4.6	21.8	399
	3	2.6	22.5	502
Alta	1	4.8	16.8	824
	2	2.9	17.7	836
BC	1	20.6	8.4	694
	2	12.8	11.3	1070
NWT	1	17.3	5.8	29
Yukon	1	5.3	15.8	30
CANADA		6.3	16.0	21,333

* The geographic zones used in the SCS (see Figure I).

** The number of envelope sets mailed (sample) as % of total permit sales.

*** The number of respondents as % of sample size.

Figure I: The geographical zones used in the SCS.


N W T
Zone 1
N W T
Zone 1
Y T
Zone 1
N W T
Zone 1
B C
Zone 1
Alta
Zone 2
Sask
Zone 2
Man
Zone 2
Nfld
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Nfld
Zone 1
B C
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Alta
Zone 1
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Sask
Zone 3
Man
Zone 1
Ont
Zone 3
Que
Zone 2
P E I
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N B
Zone 2
N B
Zone 1
N S
Zone 2
N S
Zone 1
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Zone 1
United States
Ont
Zone 2
Ont
Zone 1

10.0 APPENDIX C: THE FEEDING HABITS OF MALLARD AND BLACK DUCKS

Mallard and Black Ducks are omnivorous species (Cottam, 1939; Johnsgard, 1975; Bellrose, 1976). Mallards forage on agricultural crops as well as natural aquatic food items. Farm crops such as corn, sorghum, barley, rye, wheat, oats, rice and other available grains have been reported to be important parts of their diet. Seeds, leaves, stems and rootstalks of emergent or submergent plant species such as wild rice (Zizania sp.), pondweeds (Potomogeton sp.), smartweeds (Polygonum sp.) and bulrushes (Scirpus sp.) are also consumed. Animal matter in their diet is usually under 10 percent. Black Ducks consume a higher proportion of animal food than Mallards. Along coastal areas, molluscs can account for up to 50 percent of the total food intake. Black Ducks also feed heavily on leaves, stems and rootstalks of emergent and submerged plant species including cordgrass (Spatina sp.), sedges (Carex sp.) and bulrushes (Scirpus sp.). Since both species of waterfowl are found to frequent a great variety of habitats, their diets can vary according to the availability of the food resources.